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DETAILED PRESIMULATION REPORT FOR PHASE "A" RENDEZVOUS SIMULATION [U]

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1.0 SUMMARY

The simulation program will investigate methods of manual Rendezvous of the LEM with the CSM, and measure pilot performance during this phase of the mission for various vehicle configurations and modes of the FCS.

The program assumes the LEM nominally having completed its powered ascent trajectory and coasting in orbit with a maximum resultant range of 30 nautical miles and a closing rate with respect to the CSM. Rendezvous from an equiperiod orbit will be also investigated.

A fixed based, six degree of freedom simulation is being utilized for this study. The cockpit, located in the Blue Ball, has been sufficiently instrumented for the Rendezvous mission. It also contains a three axis T-bar controller, a translation thrust controller, and the necessary RCS mode select switches. Six degree of freedom LEM rigid body equations of motion, LEM radar data equations, RCS equations, starfield and target drive equations have been programmed for solution on analog computers located in the GAEC Analog Facility. A special purpose unit containing pulse modulators and logic solving devices has been fabricated and interfaced with the computer to provide the proper inputs to the LEM axial forces and moment terms as a function of error signal and control mode selection.

The starfield and target display system provides the pilot with sufficiently realistic visual data with which he will attempt Rendezvous during the more degraded modes of operation.

The complete experimental test matrix is detailed in Section 5.0 and will be run in the following manner. A preliminary experimental test matrix has been formulated consisting of basic control system and mass density variation experiments. Also included are the more difficult Rendezvous part tasks. The results of the above will be evaluated to provide the foundation for the remaining run schedule.

2.0 INTRODUCTION

The manual Rendezvous portion of the LEM mission will be investigated in two distinct simulations.

The Phase A study, providing design information to the various LEM engineering groups, will be run in its entirety at GAEC using available "in-house" equipment. This program is known as the Rendezvous Simulation IIA and is described in this report. The run schedule will commence in August, 1963 and run a minimum of two months.

The Phase B Rendezvous Study will be a part of the IIB Descent, Ascent and Abort Simulation. The aims of the Rendezvous portion of the IIB simulation include checkout of available LEM hardware, FMES hardware and evaluation of the latest Rendezvous and training techniques. Major facilities to be utilized include a fixed base LEM prototype cabin, higher quality visual displays, a three axis flight table, a combined analog-digital computer system and the necessary peripheral equipment. The program is scheduled to begin formal operations March 1, 1964 and be completed December 31, 1964.

2.1 Objectives of the Simulation

The major objectives of the manual Rendezvous IIA Simulation are to:

1) Evaluate manual Rendezvous methods including line of sight nulling, range and range rate nulling, and combinations of the two at various intervals.

2) Determine pilot performance in terms of fuel and time consumed, terminal range, and range rate for Rendezvous from equiperiod, low thrust, and nominal copplanar trajectories, commencing 20 to 30 miles from the CSM.

3) Verify systems operability in various degraded modes requiring manual operation and make any recommendations for system design improvements. The various levels of functional operation for manual flight control are:

   a) Radar guidance; full instrument display (PNGS failure)
   b) Radar guidance; partial instrument display (PNGS and attitude indicator failure)
   c) CSM radar guidance, voice comments; attitude display (PNGS and LEM radar failure)
   d) Visual guidance; no display (PNGS, radar, & attitude indicator failure)
   e) Flight Control System Modes with simulated noise; for single and dual failures in RCS with both jet on and jet off conditions

Other objectives of this simulation are to measure pilot/system performance for mass density variations and to adjust the FCS deadband to study vehicle response and pilot handling characteristics. In addition, the simulation will measure Rendezvous detection characteristics, attitude, LOS rate, range, and range rate limits and response characteristics and training time requirements.

3.0 SIMULATION DESCRIPTION

3.1 General

The major components (Figure 1) utilized are a LEM cabin mock-up, a visual display consisting of a starfield and target generators, four Analog computers solving the necessary equations and a RCS modulator and jet logic box. These are described in greater detail below.

3.1.1 LEM Cabin Mock-up

The LEM cabin mock-up, situated in the Blue Ball (Figure 2), contains the fixed base crew station with the necessary Rendezvous mission instruments, right handed attitude controller, left handed translation controller, and RCS mode selection panel. No attempt has been made to up-date the design configuration of the cabin to the present LEM configuration.

3.1.1.1 Cabin Instruments

The following information is presented to the pilot as an aid in Rendezvous on the cockpit instrument panel as in Figure 3 . The instrument scaling and pertinent data is detailed in Table 1 . Various instrument failure modes will be accomplished on the Analog computer.

3.1.1.2 Controllers

A three-axis T-handle finger tip controller, attached to the right arm of the pilot seat, is provided for attitude control. A built-in electrical dead zone circuit (simulating the actual controller detent switches) allows the stick dead zone to be adjusted to minimize unwanted cross-coupling. Motion beyond this dead zone produces a linear voltage as a function of position as shown in the controller calibration curve (Figure 4). In the attitude hold mode, the controller output provides proportional rate commands with the attitude hold occurring when the stick returns to neutral. Full throw sensitivity has been set in this mode at 10°/sec. In the direct minimum impulse train, minimum impulse one-shot or on-off modes, the proper output is generated when motion beyond the dead zone occurs.

The left handed translation controller, attached to the instrumentation panel as in Figure 3 , No. 1, provides three axis translation control. The translation controller is capable in the direct mode of either on-off, minimum impulse train or minimum impulse one-shot jet commands.

TABLE I

INSTRUMENT PANEL DATA

Parameter	Figure Ref. No.	Meter Type	Scaling	Remarks
LOS Azimuth and Elevation Angles (A & E)	2	Galv.	$\pm 60^{\circ}$	Presented on cross needles of "Eight Ball" attitude indicator
LOS Azimuth and Elevation Rates (W_j & W_k)	4	Galv.	± 5 mrad./sec.	
LOS Range (ρ)	5	Dual Synchro	0 - 50 n.m. 0 - 5000 ft.	
LOS Range Rate ($\dot{\rho}$)	6	Galv.	0 - 500 fps	
LEM Body Angular Rates (P, Q, R)	3	Galv.	± 15 deg./sec.	
LEM Inertial Angles (ϕ_i & θ_i)	2	Synchro	ϕ_i : Continuous θ_i : $\pm 80^{\circ}$ ψ_i : Continuous	ϕ_i & θ_i presented on z axis attitude indicator; ψ_i presented on heading dial on attitude indicator (above angles are in pilot axis).
Time Expired	7	Synchro	0-9999.9 seconds	

3.1.1.3 RCS Mode Selection and Malfunction Detection Panel

The RCS Mode Selection and Malfunction Detection Panel (Figure 5) is located on the front wall of the cockpit as shown in Figure 3 , No. 8. The RCS mode selection portion of the panel allows the pilot to select the following modes of control:

1. Rotational Motion
   a. Attitude Hold (Closed Loop)
   b. Direct Minimum Impulse Train (Open Loop)
   c. Direct "On-Off" (Open Loop)
2. Translational Motion
   a. Minimum Impulse Train (Open Loop)
   b. "On-Off" (Open Loop)

The present configuration of the modulator and jet logic box and the analog program allows the pilot to switch between the open loop modes and from closed loop to open loop modes but not from open loop to closed loop control while in flight. The rotational and translational one-shot modes may only be selected from the control panel on the modulator and jet logic box. The mode of attitude control can be selected on an individual axis basis, while translational control in the three axis must be in the same mode. The automatic and attitude command modes and the deadband select switch shown in Figure 5 have not been installed. The Malfunction Detection Panel presently contains jet pair shutoff switches with light indicators to show what switches have been thrown.

3.1.2 Visual Display

The visual display, consisting of the starfield projector and target generator, is mounted on top of the LEM cabin (Figure 2) The starfield projector provides stars of approximately one inch diameter on the inner spherical surface of the Blue Ball. This is accomplished by an approximate point light source inside a one foot diameter perforated sphere. The target generator provides a target image one half inch in size at thirty nautical miles that grows proportionally as the range decreases. A blink rate of twice per second or a constant target image is available.

The display system is mounted in a five-axis gimbal system, the two inner gimbals containing the target generator. The following are the approximate gimbal limits in the various pilot axis:

1.	Starfield pitch	$\pm 30^\circ$	
2.	Starfield roll	$\pm 30^\circ$	
3.	Starfield yaw	$\pm 30^\circ$	
4.	Target pitch	$\pm 30^\circ$	WRT Starfield Pitch Gimbal
5.	Target yaw	$\pm 15^\circ$	WRT Starfield Yaw Gimbal

3.1.3 Programmed Equations of Motion

The equations of motion are discussed in this section as to their derivation, assumptions involved and method of programming. A description of the visual display drive and instrument drive equations is also presented. The assumptions made for this simulation are as follows:

a. The CSM is assumed to be in a circular lunar orbit.

b. The relative distance between the LEM and CSM is assumed to be small compared with the CSM orbital altitude.

c. The relative angular displacement between the LEM and CSM with respect to the moon center is assumed to be small.

d. Reaction jet fuel consumption during the rendezvous mission is assumed to cause a negligible change in LEM mass, inertias, and C.G. position.

e. The exhaust gases are assumed to have no angular velocity with respect to the LEM.

f. Jet damping forces are assumed to be negligible.

g. The reaction jets are assumed to have no thrust misalignment.

The resulting equations of motion are shown in block diagram form in figure 6 , and the coordinate systems referred to in the block diagram are in figures 7 through 11 .

The inertial (XYZ) coordinate system in figure 7 has its origin at the moon's geometric center, with the XY-plane coinciding with the moon's equatorial plane and the Z-axis coincident with the moon's spin axis. The local vertical ($\xi \eta \zeta$) axes shown in figure 7 move with the LEM, with the ξ - axis pointing away from the moon's center and η and ζ axes pointing east and north, respectively. The relationship between the initial body axes (X_{Bi} , Y_{Bi} , Z_{Bi}) and local vertical is shown in figure 8 .

The translational equations of motion, derived in reference (1), describe the relative position of the LEM with respect to the CSM, and contribute to the calculation of the relative velocity between the two vehicles. With the translational equations developed in this form, the need is eliminated to first compute each vehicle's inertial velocity and position of the two vehicles. The geometry of the translational equations is shown in figure 9 .

The rotational equations of motion are referenced to the LEM body axes. Products-of-inertia terms are included in the equations so that the effects of variations in C.G. position and inertias on vehicle handling qualities may be investigated.

Figure 10 shows the order of Euler angle rotation used in the analysis.

3.1.3 (Continued)

Azimuth and elevation angles to the line of sight are referenced to the Z_B axis as shown in figure 11 because of the pilot's orientation to the LEM Z_B axis.

The equations in Figure 6 are based upon the LEM RCS jet configuration shown in figure 14.

Figure 12 (a - 1) shows the Analog simulation of the equations of motion, starfield drive and target drive equations.

(1) Reference: Burri, H. U.: "Linearized Equations of Motion of a Mass Particle in a Central Force Field", RCS Systems Memo

3.1.4 Reaction Jet Control System

This section presents a summary of the Reaction Jet Control System simulation.

Fig. 13 shows a schematic diagram of the translational and rotational control systems indicating the modes attainable in each and the feedback loops of the stability augmentation mode. The translation control is capable in the direct mode of either:

a) on-off

b) minimum impulse train, or

c) minimum impulse one-shot jet command.

The rotation control is capable of either direct mode

a) on-off

b) minimum impulse train, or

c) minimum impulse one-shot jet command

The stability augmentation mode is capable of:

a) pulse ratio modulation jet command.

The rate gyro loop and the attitude gyro loop may be failed for investigative purposes.

The attitude gyro loop is operated by a function relay, which under normal operation, transmits this signal when the rate command is within the dead zone of the rotational controller but prevents its transmission when any rate command is activated.

An analog block diagram of the control system external to the modulator box and logic box is presented in Figures 12(a-e). These figures indicate the analog computer equipment required to:

a) generate the signals necessary to activate the reaction jet pulses,

b) form the summation of axial body forces and moments,

c) provide total and sectional propellant mass flow, and

d) provide an auxiliary oscillator for a dynamic frequency response check of the problem.

The reaction jet pulses are generated by the Modulator Box. This box consists of solid state circuitry capable of accomplishing the following by individual selection:

a) Pulse Ratio Modulation

b) On-Off Control

c) Minimum Impulse Train

3.1.4 (Continued)

d) Minimum Impulse One-Shot Control

The attitude or rotational control is capable of operating in modes a, b, c and d. Mode a requires both the absolute value and the value of the error signal from the analog computer to produce a pulse ratio modulated train. Modes b, c, and d operate on computer signals directly from the pilot's rotational controller.

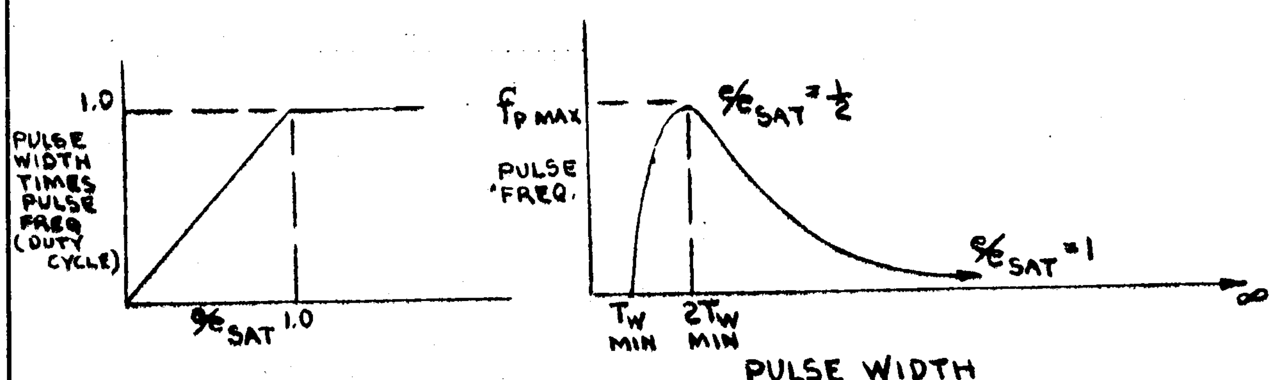
The translation or axial control is capable of operating in Modes b, c and d in response to computer signals directly from the pilot's translational controller.

The Modes a, b, c and d of the Modulator Box are described below:

3.1.4.1 <u>Mode "a" - Pulse Ratio Modulation</u>

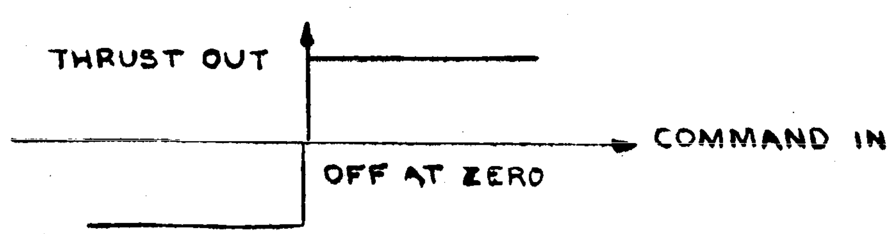
This mode has a basic minimum impulse width of 6 milliseconds with provision to select additional minimum pulse widths in increments of 6 milliseconds up to a pulse width of 30 milliseconds.

The pulse frequency is a function of the pulse width such that the product of the two varies directly with normalized error up to the point of saturation which is full on. The following sketch illustrates this operation:



3.1.4.2 <u>Mode "b" - On-Off Control</u>

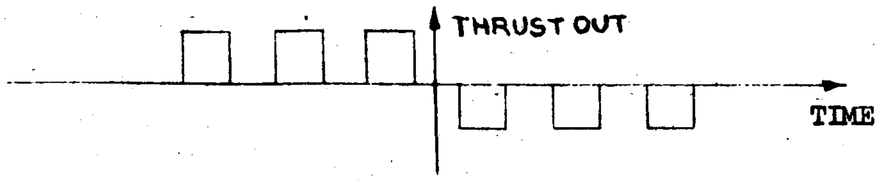
This mode is a direct signal from controller through the modulator box which provides a binary level signal to the logic box.



3.1.4.3 Mode "c" - Minimum Impulse Train

This mode provides both a fixed pulse width and fixed pulse frequency The pulse frequency is selected from a range of from 1 pulse/second to 5 pulses/second. The pulse width is selected from a range of from 6 milliseconds to 30 milliseconds.

The output is a continuous train operating at the selected pulse width and pulse frequency for as long as the controller is displaced.



3.1.4.4 Mode"d" - Minimum Impulse One-Shot Control

This mode has a pulse width capability of from 6 milliseconds to 30 milliseconds. A single pulse of the selected pulse width is generated for each control displacement.

The modulator box is fitted with indicator lights which show the operating mode. The Logic Box performs a distinctly different task than the Modulator Box but is physically located within the same housing.

The function of the logic box is to select eligible reaction jets for firing dependent upon pilot controller inputs and specific failure switch settings.

The logic box is comprised of solid state circuitry which operates in response to binary levels "0" and "1" which are set by pilot controller inputs through the analog computer. These binary levels are fed to a system of Boolean statements (shown in Table 2) which in turn activate the eligible jets for firing.

The logic box is capable of introducing a jet failure to any of the 16 reaction jets and an indicator to show pilot selection of a jet pair failure. Table 3 illustrates the test matrix utilized to check the operation of the control system modulator box and logic box prior to production running.

The pilot has a three axis translational controller mounted at his left hand position. This controller consists basically of three microswitches which transmit a fixed level signal to the analog computer upon closure of each of the X, Y, and Z axis switches. Mounted at the pilot's right hand is his attitude or rotational controller. This provides a rate command signal to the analog computer proportional to the displacement of the controller about each of the three attitude axes p, q and r. This controller has an electrical dead band built into it which may be adjusted for compatibility with mechanical slop and pilot feel. Figure 4 shows a position vs. rate command calibration curve for each axis.

Present configuration of the LEM RCS does not utilize the rotational or translational minimum impulse one shot modes. This mode will not be investigated during the IIA Rendezvous simulation.

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TABLE 2

RENDEZVOUS PHASE RCS LOGIC

Reference LMO-500-20

C = 1 enable 400 lbs along X; C = 0 enable 200 lbs along X

A = enable jets parallel to X-axis
Subscript 1,2,3,4 identifies Quad. I, II, III, IV

A = 1 normal operation; A = 0 inhibit firing - jet pair isolated

B = enable pair of jets in Y-Z plane, each Quad subscript identifies Quad No.

B = 1, 0 - Same as for A

$$T_1 = A_1 \left[Q_2A_2(R_2'X_1'+X_2A_3) + R_1A_4 \left[Q_1'X_1' + A_2A_3(X_2+Q_2)\right] + X_2Q_1' R_2'(C+A_2'+A_4') \right]$$

$$T_2 = A_1 \left[X_1(Q_2'R_1'+ Q_1A_2) A_3 + R_2\left[X_2'Q_2'(A_2'+A_3') + A_2A_3A_4(Q_1+ X_1)\right] + Q_1R_1'X_2'(A_4'+ A_3') \right]$$

$$T_5 = A_2 \left[X_2A_4(Q_2'R_2'+ Q_1 A_1) + R_1 \left[X_1'Q_2'(A_1'+A_4')+ A_3A_4A_1(Q_1+ X_2)\right] + Q_1R_2'X_1'(A_3'+A_4') \right]$$

$$T_6 = A_2 \left[Q_2A_1(R_1'X_2'+ X_1A_4) + R_2\left[(Q_1'X_2'+ A_4A_1(X_1+Q_2)\right]A_3 + X_1Q_1'R_1'(C+ A_1'+A_3') \right]$$

$$T_9 = A_3\left[Q_1A_4(R_1'X_1'+ X_2A_1) + R_2A_2\left[Q_2'X_1'+ A_1A_4(X_2+Q_1)\right] + X_2Q_2'R_1'(C+A_2'+A_4')\right]$$

$$T_{10} = A_3\left[X_1A_1(Q_1'R_2'+ Q_2A_4) + R_1 \left[Q_1'X_2'(A_1'+ A_4')+ A_1A_2A_4(X_1+ Q_2)\right] + Q_2X_2'R_2'(A_1'+A_2')\right]$$

$$T_{13} = A_4\left[X_2 A_2 (Q_1'R_1'+Q_2A_3) + R_2 \left[X_1'Q_1'(A_3'+A_2')+A_1A_2A_3(X_2+ Q_2)\right]+ Q_2R_1'X_1'(A_1'+A_2')\right]$$

$$T_{14} = A_4\left[Q_1A_3(R_2'X_2'+ X_1A_2)+ R_1 \left[Q_2'X_2'+A_2A_3(X_1+ Q_1)\right] A_1+ X_1Q_2'R_2'(C+A_1'+A_3')\right]$$

$$T_3 = B_1 \left[Z_2(B_3+ Y_1'B_3')+P_2Z_1' \left[(Y_1+Y_2)B_2B_4+ B_2'+B_4'\right]\right]$$

$$T_7 = B_2\left[Z_1(B_4 + Y_1'B_4') + P_1Z_2' \left[(Y_1+ Y_2)B_1B_3+ B_1'+B_3'\right]\right]$$

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TABLE 2 cont'd

$$T_{11} = B_3 \Big[Z_1 [B_1 + Y_2' B_1'] + P_2 Z_2' [(Y_1 + Y_2) B_2 B_4 + B_2' + B_4'] \Big]$$

$$T_{15} = B_4 \Big[Z_2 (B_2 + Y_2' B_2') + P_1 Z_1' \ (Y_1 + Y_2) B_3 B_1 + B_1' + B_3'] \Big]$$

$$T_4 = B_1 \Big[B_3 [P_1 Y_1' + Y_2 (P_2' + P_2 Z_1' Z_2')] + B_3' [P_1 Y_1' (Z_1 + Z_2) + Y_2 Z_1' (P_2' + P_2 Z_2')] + P_1 Y_1 (Z_1 B_2' + Z_2 B_4') \Big]$$

$$T_{16} = B_4 \Big[B_2 [P_2 Y_2' + Y_1 (P_1' + P_1 Z_1' Z_2')] + P_2 Y_2 (Z_1 B_3' + Z_2 B_1') + B_2' [Y_1 Z_1' (P_1' + P_1 Z_2') + P_2 Y_2' (Z_1 + Z_2)] \Big]$$

$$T_8 = B_2 \Big[B_4 [P_2 Y_1' + Y_2 (P_1' + P_1 Z_1' Z_2')] + P_2 Y_1 (Z_1 B_3' + Z_2 B_1') + B_4' [Y_2 Z_2' (P_1' + P_1 Z_1') + P_2 Y_1' (Z_1 + Z_2)] \Big]$$

$$T_{12} = B_3 \Big[B_1 [P_1 Y_2' + Y_1 (P_2' + P_2 Z_1' Z_2')] + P_1 Y_2 (Z_1 B_2' + Z_2 B_4') + B_1' [P_1 Y_2' (Z_1 + Z_2) + Y_1 Z_2' (P_2' + P_2 Z_1')] \Big]$$

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TABLE 3

LEM RENDEZVOUS SIMULATOR CONTROLLER AND LOGIC CHECK LIST

CONTROLLER	ON OFF	MIN. IMP.	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4	RECORDER VOLTS B_x	B_y	B_z	L	M	N	C sw
X_1 (+X Translation)	X										+40	0	0	0	0	0	
	X		X								+40	0	0	0	0	0	
	X			X							+40	0	0	0	0	0	
	X				X						+40	0	0	0	0	0	
	X					X					+40	0	0	0	0	0	
	X										+80	0	0	0	0	0	X
	X		X								+40	0	0	0	0	0	X
	X			X							+60	0	0	0	+6.9	+6.9	X
	X				X						+40	0	0	0	0	0	X
	X					X					+60	0	0	0	-6.9	-6.9	X
		X									X	0	0	0	0	0	
One-Shot											X	0	0	0	0	0	
X_2 (-X Translation)	X										-40	0	0	0	0	0	
	X		X								-40	0	0	0	0	0	
	X			X							-40	0	0	0	0	0	
	X				X						-40	0	0	0	0	0	
	X					X					-40	0	0	0	0	0	
	X										-80	0	0	0	0	0	X
	X		X								-60	0	0	0	+6.9	-6.9	X
	X			X							-40	0	0	0	0	0	X
	X				X						-60	0	0	0	-6.9	+6.9	X
	X					X					-40	0	0	0	0	0	X
		X									X	0	0	0	0	0	
One-Shot											X	0	0	0	0	0	
Y_1 (+Y Translation)	X										0	+40	0	0	0	0	
	X						X				0	+40	0	0	0	0	
	X							X			0	+40	0	0	0	0	
	X								X		0	+20	0	$-6\frac{1}{4}$	0	0	
	X									X	0	+20	0	$+6\frac{1}{4}$	0	0	
		X									0	X	0	0	0	0	
One-Shot											0	X	0	0	0	0	

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[redacted] TABLE 3 CONTINUED

LEM RENDEZVOUS SIMULATOR CONTROLLER AND LOGIC CHECK LIST

CONTROLLER	MODE										RECORDER VOLTS						
	ON OFF	MIN. IMP	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4	B_X	B_Y	B_Z	L	M	N	C SW
Y_2 (Y Translation)	X										0	-40	0	0	0	0	
	X						X				0	-20	0	$-6\frac{1}{4}$	0	0	
	X							X			0	-20	0	$+6\frac{1}{4}$	0	0	
	X								X		0	-40	0	0	0	0	
	X									X	0	-40	0	0	0	0	
		X									0	X	0	0	0	0	
One-Shot		X									0	X	0	0	0	0	
Z_1 (Z Translation)	X										0	0	+40	0	0	0	
	X						X				0	0	+40	0	0	0	
	X							X			0	0	+20	$-6\frac{1}{4}$	0	0	
	X								X		0	0	+20	$+6\frac{1}{4}$	0	0	
	X									X	0	0	+40	0	0	0	
		X									0	0	X	0	0	0	
One-Shot		X									0	0	X	0	0	0	
Z_2 (Z Translation)	X										0	0	-40	0	0	0	
	X						X				0	0	-20	$+6\frac{1}{4}$	0	0	
	X							X			0	0	-40	0	0	0	
	X								X		0	0	-40	0	0	0	
	X									X	0	0	-20	$-6\frac{1}{4}$	0	0	
		X									0	0	X	0	0	0	
One-Shot		X									0	0	X	0	0	0	
P_1 (L Rotation)	X										0	0	0	$+12\frac{1}{2}$	0	0	
	X						X				0	0	0	$+12\frac{1}{2}$	0	0	
	X							X			0	0	0	$+12\frac{1}{2}$	0	0	
	X								X		0	0	0	$+12\frac{1}{2}$	0	0	
	X									X	0	0	0	$+12\frac{1}{2}$	0	0	
		X									0	0	0	X	0	0	
One-Shot		X									0	0	0	X	0	0	
P_2 (L Rotation)	X										0	0	0	$-12\frac{1}{2}$	0	0	
	X						X				0	0	0	$-12\frac{1}{2}$	0	0	
	X							X			0	0	0	$-12\frac{1}{2}$	0	0	
	X								X		0	0	0	$-12\frac{1}{2}$	0	0	
	X									X	0	0	0	$-12\frac{1}{2}$	0	0	
		X									0	0	0	X	0	0	
One-Shot		X									0	0	0	X	0	0	

[redacted]

TABLE 3 CONTINUED

LEM RENDEZVOUS SIMULATOR CONTROLLER AND LOGIC CHECK LIST

CONTROLLER	MODE										RECORDER VOLTS						
	ON OFF	MIN IMP.	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4	B_X	B_Y	B_Z	L	M	N	C SW
Q_1 (M Rotation)	X										0	0	0	0	$+12\frac{1}{2}$	0	
	X		X								0	0	0	0	$+12\frac{1}{2}$	0	
	X			X							0	0	0	0	$+12\frac{1}{2}$	0	
	X				X						0	0	0	0	$+12\frac{1}{2}$	0	
	X					X					0	0	0	0	$+12\frac{1}{2}$	0	
		X									0	0	0	0	X	0	
One-Shot		X									0	0	0	0	X	0	
Q_2 (M Rotation)	X										0	0	0	0	$-12\frac{1}{2}$	0	
	X		X								0	0	0	0	$-12\frac{1}{2}$	0	
	X			X							0	0	0	0	$-12\frac{1}{2}$	0	
	X				X						0	0	0	0	$-12\frac{1}{2}$	0	
	X					X					0	0	0	0	$-12\frac{1}{2}$	0	
		X									0	0	0	0	X	0	
One-Shot		X									0	0	0	0	X	0	
R_1 (R Rotation)	X										0	0	0	0	0	$+12\frac{1}{2}$	
	X		X								0	0	0	0	0	$+12\frac{1}{2}$	
	X			X							0	0	0	0	0	$+12\frac{1}{2}$	
	X				X						0	0	0	0	0	$+12\frac{1}{2}$	
	X					X					0	0	0	0	0	$+12\frac{1}{2}$	
		X									0	0	0	0	0	X	
One-Shot		X									0	0	0	0	0	X	
R_2 (R Rotation)	X										0	0	0	0	0	$-12\frac{1}{2}$	
	X		X								0	0	0	0	0	$-12\frac{1}{2}$	
	X			X							0	0	0	0	0	$-12\frac{1}{2}$	
	X				X						0	0	0	0	0	$-12\frac{1}{2}$	
	X					X					0	0	0	0	0	$-12\frac{1}{2}$	
		X									0	0	0	0	0	X	
One-Shot		X									0	0	0	0	0	X	

4.0 DATA RECORDING PROCEDURE

The Simulation output data will be available in two forms, Analog voltages on strip chart recorders and x-y plotters and digital printout from a digital processing of Analog tapes.

Thirty-eight strip chart recorder channels will be available to record the requested data as a function of time. Unused channels will monitor the more critical portions of the simulation to assure proper operation. Two x-y plotters will be utilized to plot requested parameters as a function of a program variable other than time. Seven channels of Analog tape will be time-shared by use of special purpose multiplexers, A-D conversion equipment (located at the Peconic facility) and other peripheral equipment to generate thirty-two channels of digital printout. This data will verify the terminal readings that are made at the end of each Rendezvous run at the request of the design groups. The data in this form will allow a more qualitative analysis of the recorder parameters during the total run.

The various design groups concerned with the subject matter of the experimental test matrix have selected their required parameters and the method of recording. The selections have been evaluated as to availability and the recording form requested. Conflicts that appeared from this evaluation have been satisfactorily resolved.

The design groups requesting data have been directed to have cognizant personnel available to monitor the traces as the test matrix runs of interest are being performed to assure proper data recording and simulation solution.

5.0 EXPERIMENTAL TEST PLAN

5.1 Purpose

The major concern of this simulation is to determine the range of expected pilot performance for accomplishing Rendezvous under the various vehicle configurations and multiple malfunction conditions proposed. The trajectories followed will minimize noncoplanar conditions while evaluating alternate flight control characteristics under manually guided Rendezvous. Man's ability to act as a manager and programmer of fuel expenditures and some of his visibility requirements will also be investigated. In this section are contained the information summation and requirements of those groups interested in the Rendezvous simulation. The number of problems posed by these groups precludes resolution of them within the two month experimental period. Hence a priority has been established to achieve a maximum possible benefit from this phase A simulation. Every three weeks a review of the simulation will be conducted to determine priority, experimental design, and/or vehicle changes which effect the conduct of the experiment. The necessary and feasible changes in the simulation will be implemented.

5.2 Experimental Description

5.2.1 General

The number of variables to investigate is large and hence an integrated study of them all simultaneously becomes unwieldy. A series of smaller experiments is planned with the aim of developing one or two "best" systems for evaluation during the IIB simulation effort.

Two discrete types of experiments will be performed. The first three investigations are preliminary ones designed to aid in defining and tuning up the simulation system. The next two experiments will be used to determine human performance data. The experiments will be conducted in the following order:

Preliminary Investigations

1. Determination of Mass Density Property Effects on the FCS
2. Establishment of Flight Control System Characteristics
3. Validation of Rendezvous Trajectory Techniques

Human Performance Investigations

4. Pilot Performance in Achieving Rendezvous under Varying Degrees of Information Degradation.
5. Pilot Performance with Flight Control System Degradations

Where it becomes feasible, portions of experiments will be combined.

5.2.2 Subject Program

Each pilot participant will be subjected to the following program:

1. Indoctrination
2. Pretraining in part task segments
3. Qualification in part task segments
4. Pretraining in Rendezvous task
5. Qualification in Rendezvous task
6. Experimental tests

In the indoctrination phase, a verbal description of the Rendezvous problem, the limitations of the simulation, the flight control system and its dynamics, the vehicle configurations that the subject will be flying, and the criteria he has to meet for each part task segment and full task will be given. A brief resume of the tasks required will also be given. The subject will be shown the simulator and each control and display function and operation will be explained. The automatic trajectory, normally used for the dynamic check, will be used as a demonstration of an acceptable Rendezvous. Critical points in the trajectory will be shown to the subject as well as how the various displays function during a dynamic situation. Of special interest will be the target and starfield displays and their respective motions as the LEM achieves Rendezvous.

Part task training will be concerned with four task segments:

1. Nulling LOS rates

2. Bringing range and range rate to specific values

3. Making one correction step. (Control LOS rate, Range, Range Rate)

4. Making a series of correction steps

Two different methods of visually nulling line of sight rates will be taught to the subjects until such time as a decision is made concerning the one best technique. Thereafter, only the best technique will be taught. In addition, an all instrument technique will be taught in which the window shall only be used as a check on the instruments. Instruction in controlling range and range rate will be limited to a single method. Once some proficiency has been achieved in the two above listed part tasks, the subject is to follow a specific schedule of correction steps as a function of range from some target, e.g., the CSM.

To define at least one common point on their respective learning curves, each subject will qualify in each of the the tasks described above. Qualification means meeting certain time, fuel, accuracy, and rate criteria for each task in at least three out of five attempts. The suggested criteria follow:

5.2.2 Subject Program (Cont.)

Estimated Qualification Criteria

	Null LOS Rate	Control Range and Range Rate
Time	15 seconds	300 seconds
Fuel (ΔV -fps)	5 fps	400 fps
Accuracy	$\pm$10 millirad/sec.	$\pm$10 fps

Note: Range change is 5 nautical miles; Range Rate change is 1 mile/minute

The subject will be asked to apply his basic skills of nulling line of sight rates and controlling range and range rates to various trajectories, different initial conditions, as part of his future pretraining in Rendezvous. Increased competance in the part tasks will be expected as additional training in alternate trajectories is provided. The last step in the training sequence will be to qualify each subject in at least two separate trajectories in each of the various Rendezvous techniques.

5.3 Experimental Designs

5.3.1 Experiment One - Mass Density Effects

For this experiment, a nominal flight control system, analytically developed, will be used while the following are varied: Six positions of the center of gravity, one moment of inertia set, and three products of inertia sets. Pilot performance will be determined for a task comparable to controlling range and range rate, by measuring pilot ability to attain a precise position and attitude, his fuel consumption to perform the task, and the time per run.

An estimate of propellant usage, as the center of gravity position is changed and as the products of inertia are varied, is required to provide data on the fuel usage for the total Rendezvous task. A sequence of test runs to obtain this data is presented in Table 4 . Figure 14 , RCS Jet Moment Arms Definition and Table 5 RCS Jet Moment Arms Lengths for Experiment One, details the characteristics of the RCS jet moment arms for this experiment.

TABLE 4

MASS DENSITY VARIATIONS

Run	CG Position			Products of Inertia			Moments of Inertia		
Nos	X	Y	Z	Iyz	Ixz	Ixy	Ix	Iy	Iz
1	249	0	0	-10	160	-50	2212	2025	1294
2	249	1	1	"	"	"	"	"	"
3	249	3	3	"	"	"	"	"	"
4	247	0	0	"	"	"	"	"	"
5	247	3	3	"	"	"	"	"	"
6	249	0	0	200	400	200	2212	2025	1294
7	249	2	2	"	"	"	"	"	"
8	249	0	0	400	800	400	2212	2025	1294
9	249	3	3	"	"	"	"	"	"

TABLE 5

RCS JET MOMENT ARM LENGTHS FOR EXPERIMENT ONE

Run	X_1	Y_1	Y_2	Y_3	Y_4	Z_1	Z_2	Z_3	Z_4
1	0.000	5.000	5.000	5.500	5.500	5.500	5.500	5.000	5.000
2	0.000	4.917	5.083	5.417	5.583	5.417	5.583	4.917	5.083
3	0.000	4.750	5.250	5.250	5.750	5.250	5.750	4.750	5.250
4	-2.000	5.000	5.000	5.500	5.500	5.500	5.500	5.000	5.000
5	-2.000	4.750	5.250	5.250	5.750	5.250	5.750	4.750	5.250
6	0.000	5.000	5.000	5.500	5.500	5.500	5.500	5.000	5.000
7	0.000	4.833	5.167	5.333	5.667	5.333	5.667	4.833	5.167
8	0.000	5.000	5.000	5.500	5.500	5.500	5.500	5.000	5.000
9	0.000	4.750	5.250	5.250	5.750	5.250	5.750	4.750	5.250

5.3.2 Experiment Two: Flight Control System Characteristics

To establish the best set of operating characteristics of the flight control system for the Rendezvous simulation, a series of runs will be made using a nulling the line of sight rate task to verify FCS response characteristics and define vehicle dead zones. Table 6 presents the series of runs and the characteristics to be evaluated per run.

Proportional rate command with and without attitude hold and direct pulse train and on-off reaction control modes will be used to establish flight control handling characteristics.

TABLE 6

FCS TEST MATRIX PARAMETERS

Set No.	K_{MX}	K_{RX}	$K_{\theta X}$	d_x	K_{MY}	K_{RY}	$K_{\theta Y}$	d_y	K_{MZ}	K_{RZ}	$K_{\theta Z}$	d_z	J	K_{RS}
1	265	.30	1.0	0.1°	265	.30	1.0	0.1°	265	.30	1.0	0.1°	.015	10°/sec.
2	"	"	"	0.5°	"	"	"	0.1°	"	"	"	0.1°	.015	"
3	"	"	"	1.0°	"	"	"	1.0°	"	"	"	1.0°	.015	"
4	"	"	"	2.5°	"	"	"	1.0°	"	"	"	1.0°	.015	"
5	"	"	"	2.5°	"	"	"	2.5°	"	"	"	2.5°	.015	"
6	"	"	"	5.0°	"	"	"	2.5°	"	"	"	2.5°	.015	"

Note: Forward Loop (K_M) Gains are Pounds per Degree per Jet

5.3.3 Experiment Three: Rendezvous Trajectory Characteristics

The purpose of this experiment is to establish efficient techniques for achieving manual mode Rendezvous from trajectory positions at which the vehicle may be (and still Rendezvous) for an initial range of 20-30 nautical miles from the CSM. Three trajectories, employing three sets of initial conditions, will be investigated. Two of them may be considered typical trajectories and one abort (90° synchronous or equiperiod orbit) in which the vehicle does not attempt to land on the lunar surface, but passes through pericynthion and coasts to the vicinity of the point of prior separation from the CSM. To establish the most desirable trajectory characteristics, this investigation will be divided into four parts as follows:

1. Nulling Line of Sight Rates
2. Range and Range Rate Control
3. Rendezvous Techniques
4. Correction Step Sequence

5.3.3.1 Nulling LOS Rates

Two methods of nulling LOS rates will be investigated to determine which method is most efficient from a time viewpoint, consumes the least amount of fuel, and enables the pilot to maintain nulled LOS rates most precisely. One of the two LOS methods introduces the subject to the restrictions imposed by the Primary Navigation and Guidance System IMU on the vehicle rotations which can be tolerated. In other words, IMU Gimbal lock can occur if the "X" body axis is rotated to within 25° of being perpendicular to the orbital plane of the CSM. In the Backup Guidance System, a discontinuity in the attitude information presented to the pilot occurs in a similar condition, but does not result in a gimbal lock situation. Hence, it is only necessary to look at the case where the Primary Guidance System is functional, but the man is flying the vehicle. The effect on LOS Method Two is to require that the smallest component of the line of sight rate to be nulled by pilot rolling the vehicle. It is the pilot's decision, which component should be nulled, i.e., which is the smallest one. To aid him in making this decision, the ILS type indicator which displays the two components of inertial line of sight rate will have eight areas noted in which directions will be given as to pilot roll rotation. Hence, when the two needles intersect within one of these eight areas, the pilot need only follow directions. Table 7 represents the run schedule for this phase.

TABLE 7

LOS RATE NULLING METHODS

TECHNIQUE	LOS Method One		LOS Method Two	
SEQUENCE	W_j & W_k to zero concur-rently	W_j & W_k to zero one comp-onent at a time	Pilot Roll vehicle to zero W_k; translate to zero W_j. *	Pilot Roll vehicle to zero W_j; translate to zero W_k. **
TRAJECTORY I.C.	90° synch 140° -2%	90° synch 140° -2%	90° synch 140° -2%	90° synch 140° -2%

* W_k is the smallest component. ** W_j is the smallest component.

5.3.3.2 Range and Range Rate Control

Range and range rate control will be studied by instructing the pilots to fly to a specific spatial position, arriving there within a specified envelope of attitudes and rates. The magnitude of his thrusts with the RCS and the direction will be determined by each subject. Table 8 lists the runs.

TABLE 8

RANGE AND RANGE RATE CONTROL TEST MATRIX

Terminal Positions	s = 6000 ft. h = 50,000 ft. z = 0		s = 8000 ft. h = 65,000 ft. z = 0	
Velocities (Terminal) $\dot{s}$ =	30 fps	75 fps	30 fps	75 fps
$\dot{h}$ =	0	0	0	0
Initial Position & Velocities	s = 16,000 ft. h = 80,000 ft. z = 0 $\dot{s}$ = 100 fps $\dot{z}$ = 0 $\dot{h}$ = 150 fps			

5.3.3.3 Rendezvous Techniques

The desireability of controlling range and range rate prior to nulling the line of sight rates will be studied by following the schedule listed in Table 9. A complete Rendezvous trajectory will not be used herein; only a limited portion of the trajectory is necessary.

TABLE 9

RENDEZVOUS TECHNIQUES TEST MATRIX

Technique	ONE			TWO		
Sequence	a) LOS Rate Control b) ρ & $\dot{\rho}$ Control			a) ρ & $\dot{\rho}$ Control b) LOS Rate Control		
Trajectory I.C.	180° Nom.	90° synch	140°, -2%	180° Nom.	90° synch	140°, -2%

5.3.3.4 Correction Step Schedules

The various correction step schedules for each initial condition set will be investigated by having the pilot subjects fly complete Rendezvous trajectories. Each correction step, composed of a nulling of line of sight rates and a bringing of range and range rate to specific values, will be introduced as a function of range from the CSM. Two different schedules of correction steps will be used. Table 10 represents the run sequence.

TABLE 10

CORRECTION STEP SEQUENCE

I.C. Trajectory	180° Nom.		140° -2% Thrust		90° Synchronous	
Correction Steps Schedule (Range Points in nautical miles)	20 16 12 8 4 1	20 15 10 5 2 1	20 16 12 8 4 1	20 15 10 5 2 1	20 16 12 8 4 1	20 15 10 5 2 1

5.3.4 **Experiment Four: Degraded Information Rendezvous**

It is the intent of this experiment to determine man's performance if all the information he requires to achieve Rendezvous is not available or is not presented in the most expeditious form for his immediate use. A nominal 160° central angle transfer trajectory will be used upon which the initial conditions will be based for full trajectory runs. The flight control system mode used will be Rate Command with Attitude Hold. Three different tasks with four levels of displayed information will be presented to the pilot. Failures which when introduced result in the degraded information levels, range from a Primary Navigation and Guidance System (PNGS) failure to a concurrent breakdown of PNGS, Attitude Indicator and the Rendezvous Radar.

1. Information level "None" (See Table 11) is equivalent to a PNGS failure or a choice by the man to fly the vehicle manually. All vehicle systems are operational; all necessary Rendezvous information is presented to the pilot. Hence, this condition provides base data with which to compare man's performance in the degraded modes.
2. Lack of attitude information (θ, ϕ, ψ) results from a failure of the PNGS and the attitude indicator. Hence, the control system is maintained in a rate command with attitude hold mode, but the pilot is denied body attitude position information.
3. A radar system failure (A, E, W_j, W_k) eliminates all line of sight radar information except that provided by the CSM radar. Said radar can provide range, range rate, and total line of sight inertial rate (W) via the communication link. The observer will take the part of the CSM pilot.
4. In the last mode, a visual Rendezvous is hypothesized. Multiple failures must have occurred in order for man to rely on a visual rendezvous technique; this includes failures of the PNGS, Radar and Attitude Display. The flight control mode remains as Rate Command with Attitude Hold.
5. The three types of task performances required of the subjects (under the four information levels) include:
   a) Nulling Line of Sight Rates
   b) Controlling Range and Range Rate
   c) Flying Complete Rendezvous Trajectories.

The first two tasks will be used to determine accuracy losses due to the degraded information available along with the costs in time and fuel to accomplish each maneuver. The last task will represent a summation of the individual trajectory part tasks that were investigated plus the obtaining of performance data for the whole Rendezvous task. Table 11 lists the possible information degradation conditions. Two visual Rendezvous methods are presented after the table.

TABLE 11

INFORMATION DEGRADATION TEST MATRIX

TASK TO BE PERFORMED	NULLING LOS RATES				CONTROLLING RANGE AND RANGE RATE				COMPLETE RENDEZVOUS TRAJECTORIES			
INFORMATION NOT AVAILABLE FOR CREW USE	NONE	θ ϕ ψ	A E LOS RATES	θ ϕ ψ A, E LOS RATES	NONE	θ ϕ ψ	A E LOS RATES	θ ϕ ψ A, E LOS RATES	NONE	θ ϕ ψ	A E LOS RATES	θ ϕ ψ A, E LOS RATES
IMPLIED FAILURES	PNGS	PNGS ATTITUDE DISPLAY	PNGS RADAR	PNGS RADAR ATTITUDE DISPLAY	PNGS	PNGS ATTITUDE DISPLAY	PNGS RADAR	PNGS RADAR ATTITUDE DISPLAY	PNGS	PNGS ATTITUDE DISPLAY	PNGS RADAR	PNGS ATTITUDE DISPLAY RADAR

5.3.4.1 **Visual Rendezvous Method One**

1. Detect CSM in the starfield.
2. Pilot yaw vehicle to bring CSM to window (reticle) centerline.
3. Pilot pitch vehicle up or down to bring CSM to window (reticle) center.
4. Monitor distance between reference star(s) and CSM for at least ten seconds.
5. Thrust along "y" body axis in the direction of motion to bring W_k component to zero.
6. Monitor distance between reference star(s) and CSM for at least ten seconds.
7. Thrust along "x" body axis in the direction of CSM motion to bring W_j component to zero.
8. Monitor star reference - CSM distance.
9. Maintain CSM in center of display.
10. Maintain distance between star reference(s) and CSM constant.
11. Decrease range and range rate according to schedule by firing "z" body axis jets.
12. Monitor position of CSM WRT the star reference(s).
13. Repeat steps 1-12 as required.
14. Return vehicle to "Neutral" position.

5.3.4.2 **Visual Rendezvous Method Two**

1. Detect CSM in the starfield.

2. Pilot yaw vehicle to bring CSM to window (reticle) center line.

3. Pilot pitch vehicle up or down to bring CSM to window (reticle) center.

4. Pilot roll to bring starfield and CSM motion parallel to vertical lines of window (reticle). Direction of pilot roll is determined by the position of the CSM and the reference axis on the reticle. Roll toward the axis which is nearest to the CSM.

5. Monitor distance between reference star(s) and CSM for at least ten seconds.

6. Thrust along "x" body axis in direction of increase or decrease of star-CSM distance.

7. Monitor star reference - CSM distance.

8. Maintain CSM in center of display.

9. Maintain starfield-CSM motion parallel to vertical lines on window (reticle).

10. Maintain distance between star reference and CSM constant.

11. Decrease range and range rate according to schedule by firing "z" body axis jets.

12. Monitor position of CSM WRT the star reference.

13. Repeat steps 1-12 as required.

14. Return vehicle to "Neutral" position.

5.3.5 Experiment Five: FCS Degradation Runs

This study will be conducted to evaluate man's performance under varying modes of manual flight control in the conduct of part and whole task Rendezvous. Four FCS modes and three levels of electrical White noise will be introduced into the investigation. The White noise is fed into the flight control system at the junction of the command and feedback signals from which the error signal is generated. Table 12 is the run schedule.

5.3.5 Experiment Five: FCS Degradation Runs (Cont.)

As a separate segment of this experiment an evaluation of man's ability to detect and react to an "on" type jet failure will be conducted. The standard nulling LOS rates and range and range rate control task will be used as the task from which measurements of performance will be made. Table 13 is the run schedule.

Jets failed "on" ultimately must be turned off. In this simulation the eight toggle switches are used to turn off jet couples. Hence, e.g., if jets 5 and 9 fail, then jets 5 and 8 in Quad II and 9 and 12 in Quad III would not be available. Jets failed "off" must also be turned off via the same toggle switches. This is necessary as a safety precaution (in the real world). Table 14 lists each toggle switch and the jets it can turn off. Figure 14 presents the jet configuration by number and quad.

TABLE 12

FCS DEGRADATION TEST MATRIX

RCS Control Mode	Rate Command With Attitude Hold			Rate Command			Direct Pulse in the Pitch Axis			Direct in the Pitch Axis		
White Noise Degradation	None	½x Dead-band	2x Dead-band	None	½x Dead-band	2x Dead-band	None	½x Dead-band	2x Dead-band	None	½x Dead-band	2x Dead-band

TABLE 13

ON TYPE JET FAILURE TEST MATRIX

Jet Failures	#1		#9		#15		#5 & #9	
Failure Type	ON	OFF	ON	OFF	ON	OFF	ON	OFF

TABLE 14

JET COUPLE "ON-OFF" CONTROL

Toggle Switch	Quad.	Jets Affected	System
1	I	1 & 3	A
2	II	6 & 7	A
3	III	9 & 12	A
4	IV	14 & 16	A
5	I	2 & 4	B
6	II	5 & 8	B
7	III	10 & 11	B
8	IV	13 & 15	B

5.4 **Performance Measures**

Measures of LEM performance fall into two categories: Whole task and Part task performance.

1. Whole Task measures are as follows:

   a) Terminal range
   b) Terminal range rate
   c) Total RCS jet fuel used
   d) Total time per run

2. Part Task measures are:

   a) Time to detect CSM in Starfield (measured from run start to precise pointing of "Z"body axis at CSM)
   b) Time to perform correct action for "on" type jet failure. Time for "off" type failure. (Run start to quad shut off)
   c) Time to null LOS rate to 0.1 milliradians/second
   d) Time to bring range and range rate to specific values.
   e) Accuracy with which range and range rate can be brought to specific value.
   f) Number of runs required to train subject to a specific criteria.
   g) RCS fuel consumed per null LOS rate step
   h) RCS fuel consumed per range and range rate correction step
   i) Accuracy with which LOS rate of 0.1 mills-rad can be maintained for unit time period.

5.5 Experimental Conditions

Three sets of initial conditions are presented in Table 14 for each of the several trajectories of interest in this simulation. They represent approaches to the CSM from three of the four quadrants in the plane of the CSM orbit. In terms of CSM coordinates, this means approaches from the lower left, lower right, and upper right hand quadrants will be the only ones simulated.

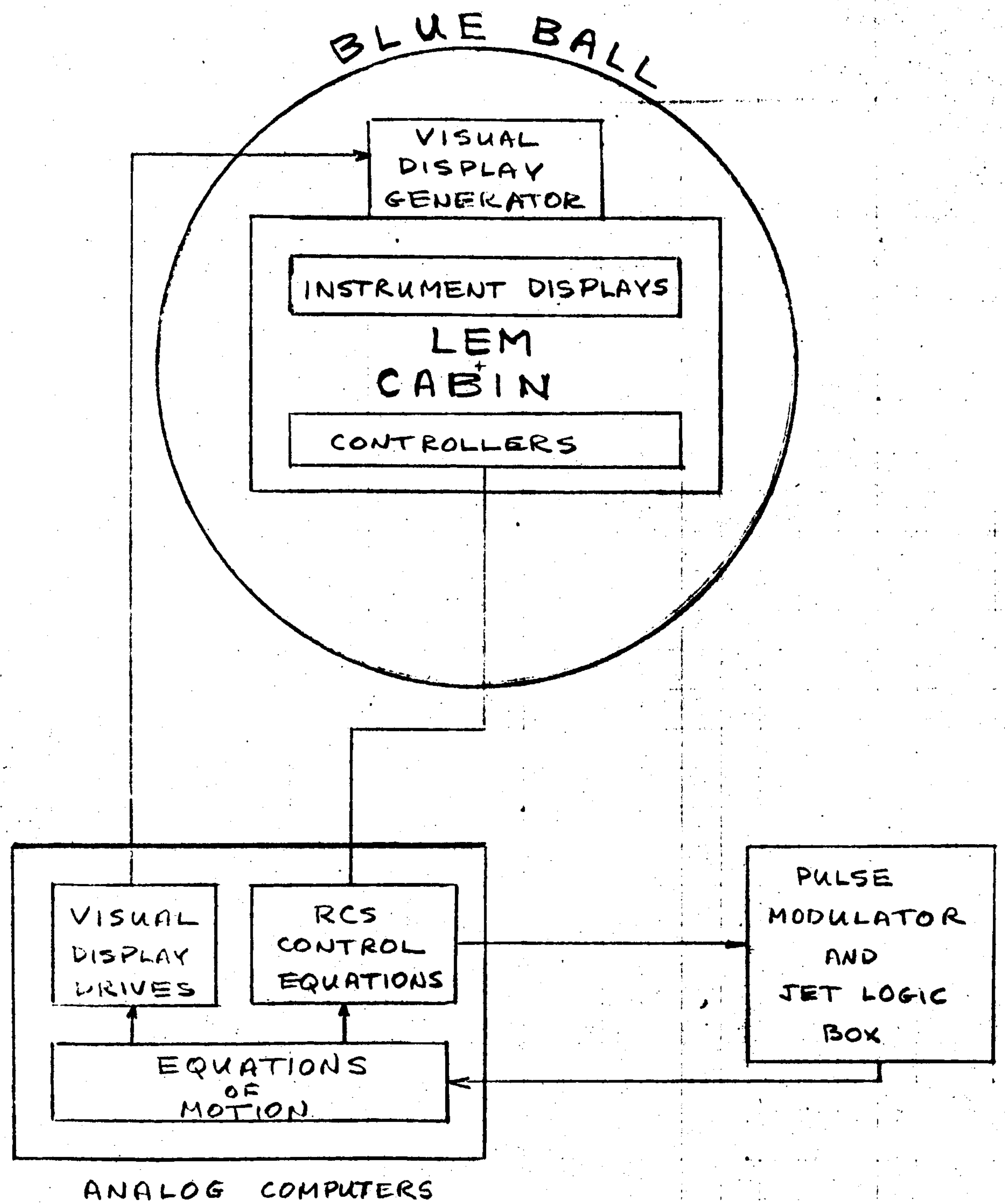
TABLE 15

RENDEZVOUS TRAJECTORY CONDITIONS

PARAMETER	180° NOMINAL	160° NOMINAL	140°, -2%	90° SYNCH.
$\dot{s}$	-138.881 ft/sec.	-126.339747 ft/sec.	-58.627 ft/sec.	+198.2385 ft/sec.
$\dot{h}$	+180.0094 ft/sec.	+185.68098 ft/sec.	+237.84372 ft/sec.	+249.02242 ft/sec.
$\dot{z}$	0	0	0	0
s	-1.612233×10^4 ft.	-1.3106312×10^3 ft.	-1.157057×10^5 ft.	-4.466315×10^4 ft.
h	-1.3680982×10^5 ft.	$+1.2765011 \times 10^5$ ft.	-7.92143×10^4 ft.	$+1.329454 \times 10^5$ ft.
z	0	0	0	0
θ	+186.72°	+180.58°	+235.97°	-18.55°
ϕ	0	0	0	0
ψ	0	0	0	0
P	0	0	0	0
Q	0.14325°/sec.	0.14325°/sec.	0.14325°/sec.	0.14325°/sec.
R	0	0	0	0
ρ_o	22.668 nm.	21.008 nm.	22.975 nm.	23.102 nm.
Time to 20 nm	≈106 sec.	≈ 31 sec.	≈220 sec.	≈65 sec.
Time from 20 nm to 0	≈1300 sec.	≈1240 sec.	≈1600 sec.	≈1100 sec.

5.6 Data Processing and Analysis

Separate measures of vehicle performance will be recorded on which analyses will be performed. Parameters measured are listed in Appendix A. Selected parameters will have the data sample mean and range calculated. Some pertinent measure of performance will be analyzed using the analysis of variance technique from which sources of deviation from chance happenings can be determined. Predictive statements about pilot performance in the Rendezvous task can be made based on these analyses. An IBM 7094 Analysis of Variance Program is available with which rapid data analysis can be performed.



MAJOR RENDEZVOUS SIMULATION COMPONENTS

FIGURE 1

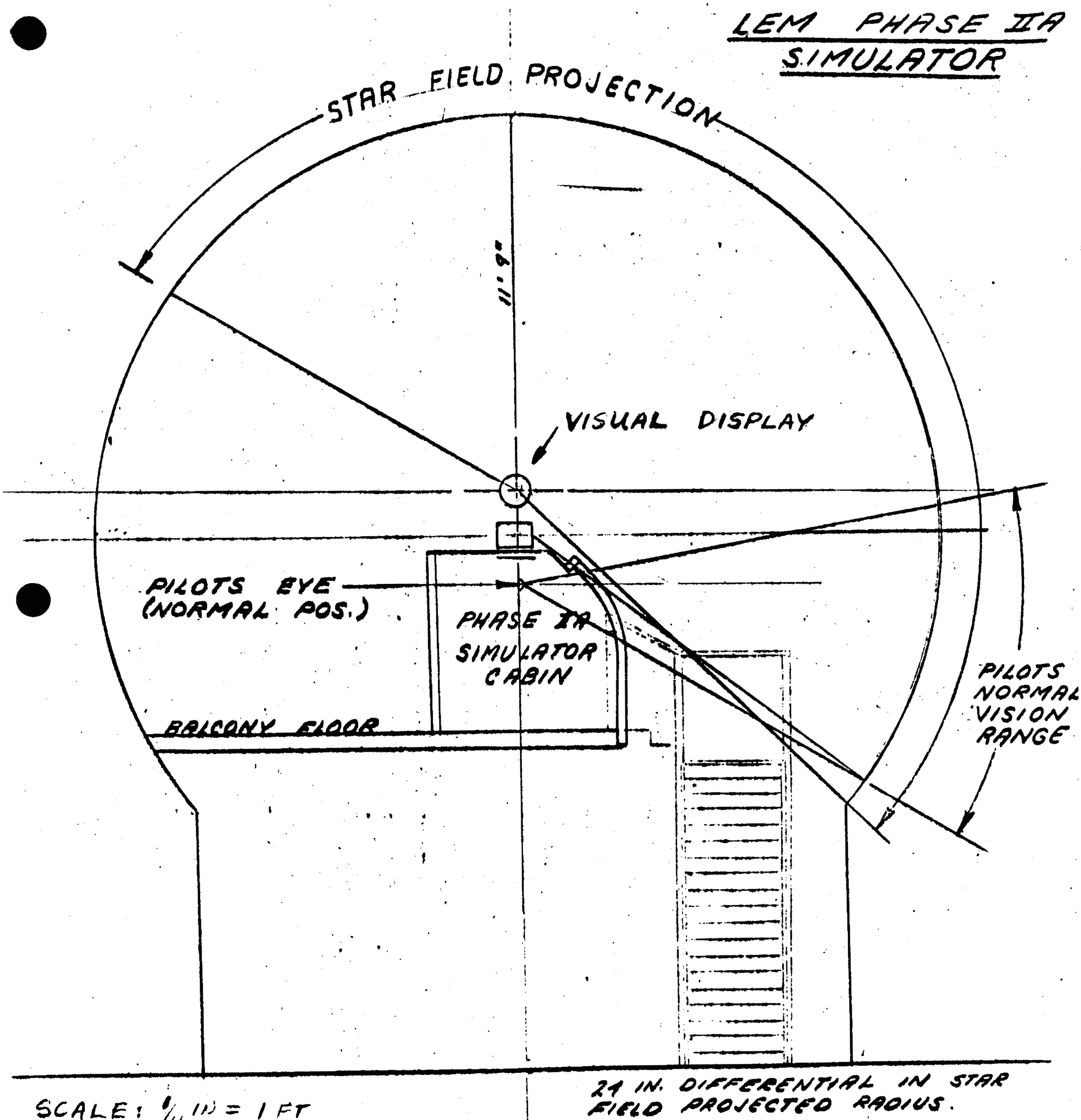
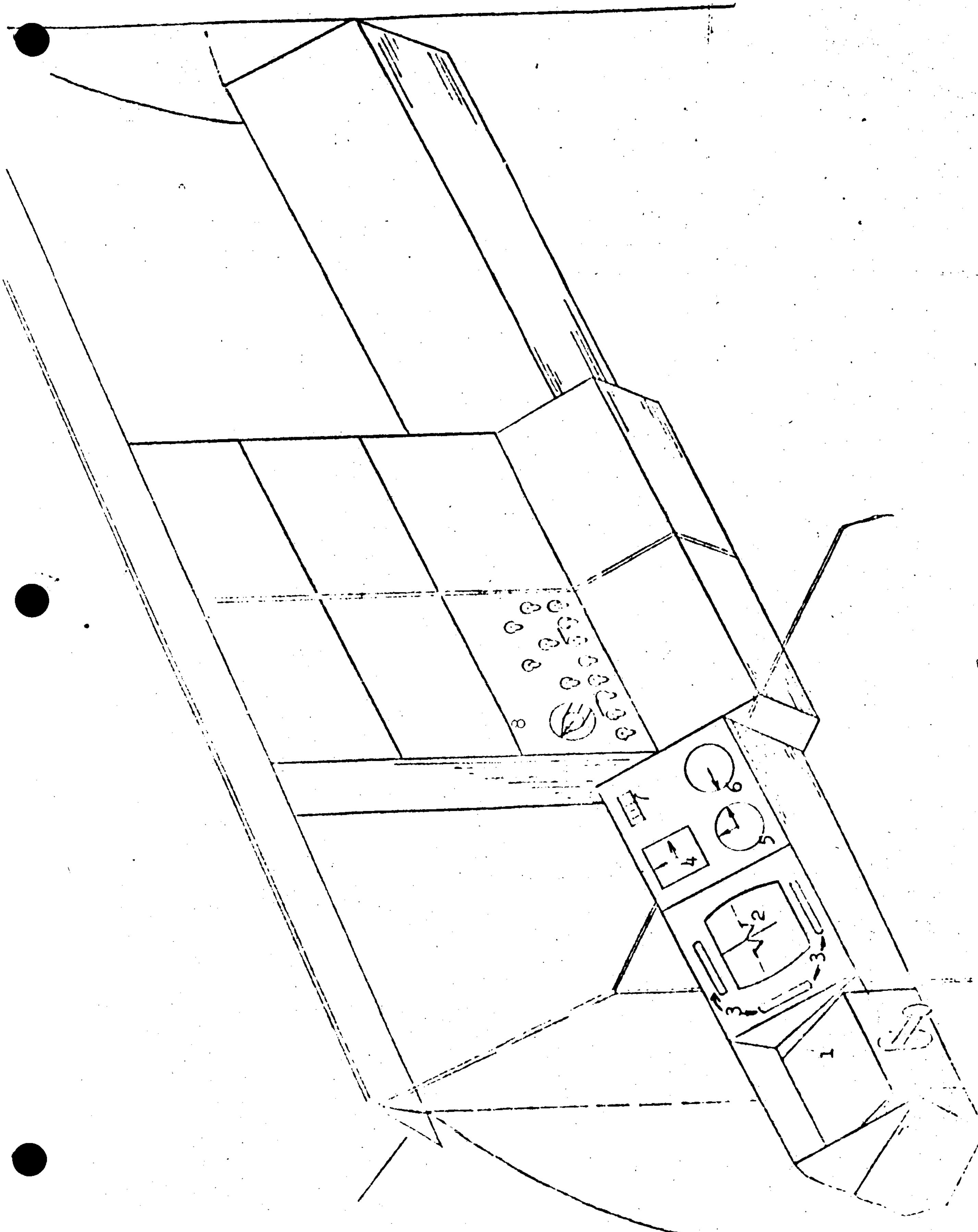


FIGURE 2 THE BLUE BALL



PHASE "A" RENDEZVOUS COCKPIT MOCKUP

FIGURE 3

CONFIDENTIAL

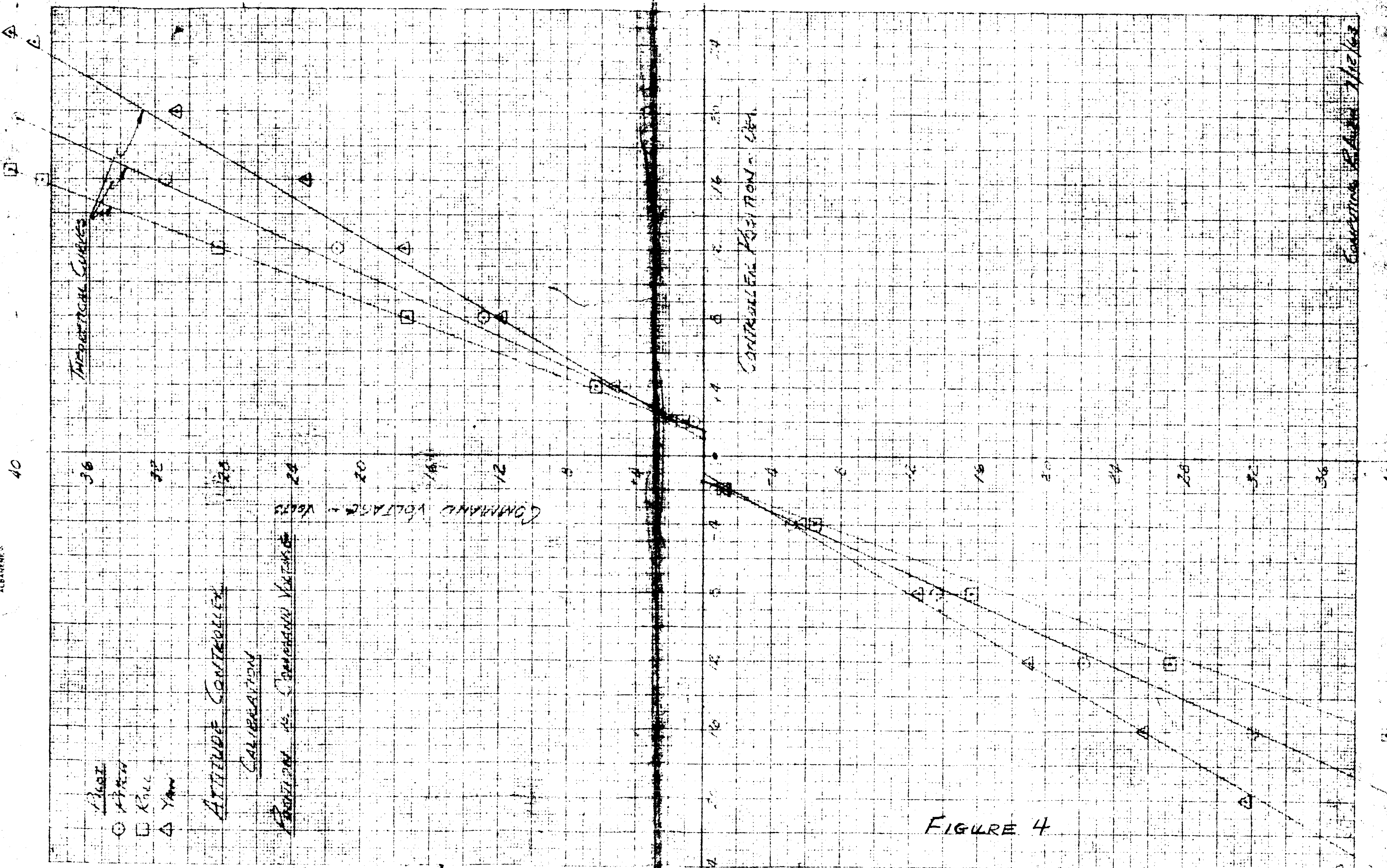


FIGURE 4

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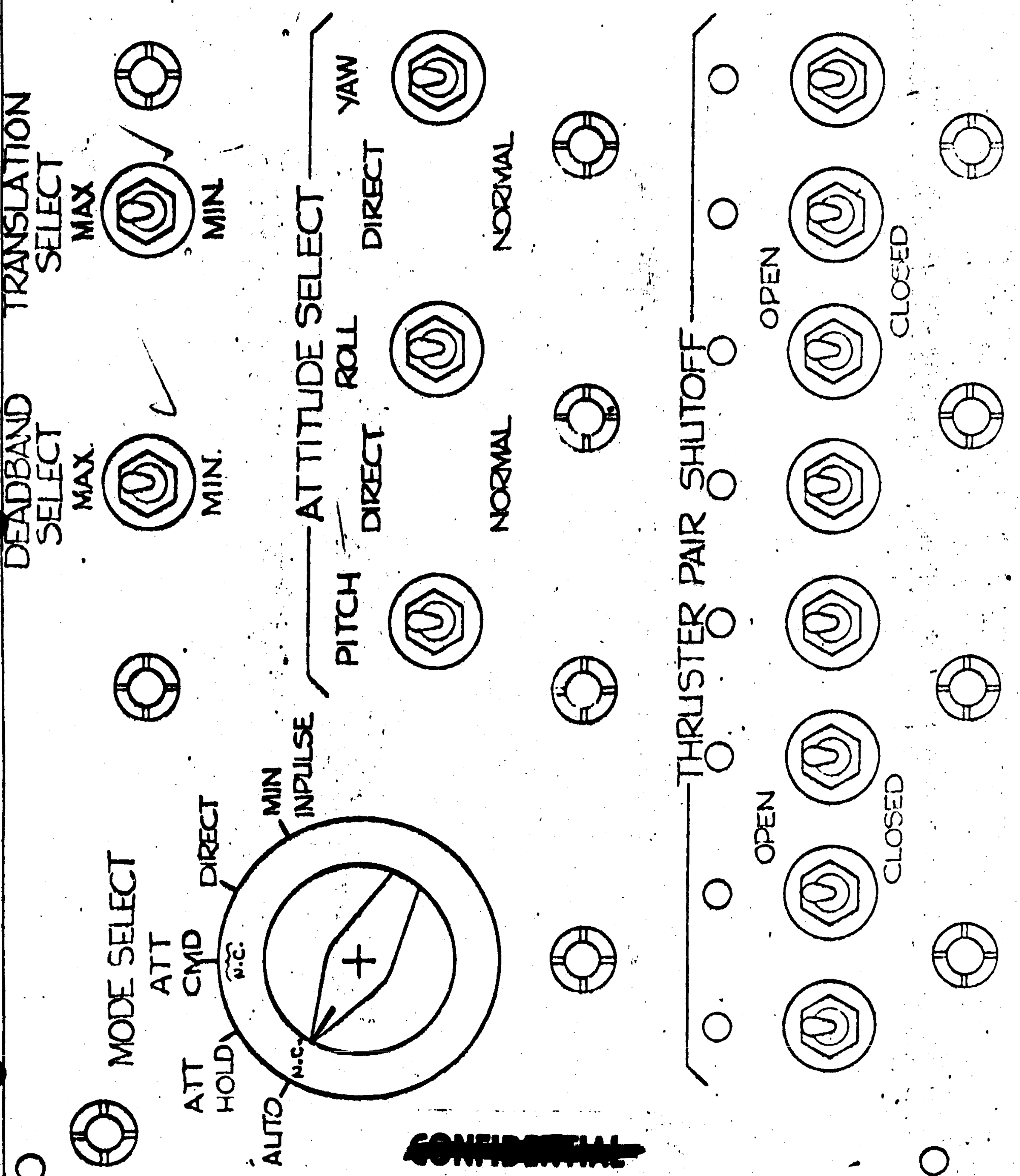
REPORT: LED 750-3
DATE: August 5, 1963

FIGURE 5

THE RCS MODE SELECTION AND MALFUNCTION DETECTION PANEL



COMPLETE EQUATIONS FOR THE LEM RENDEZVOUS SIMULATOR

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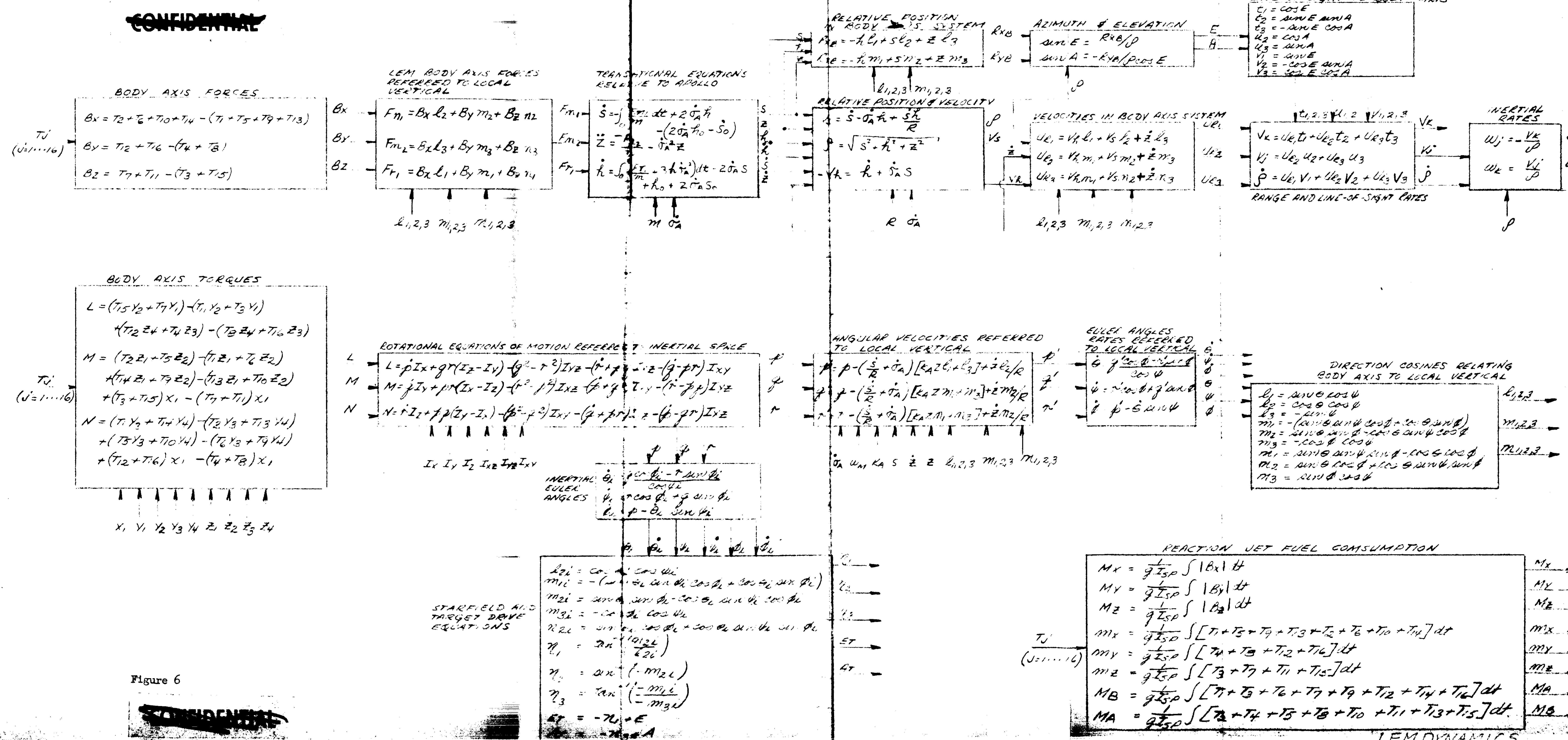

Figure 6

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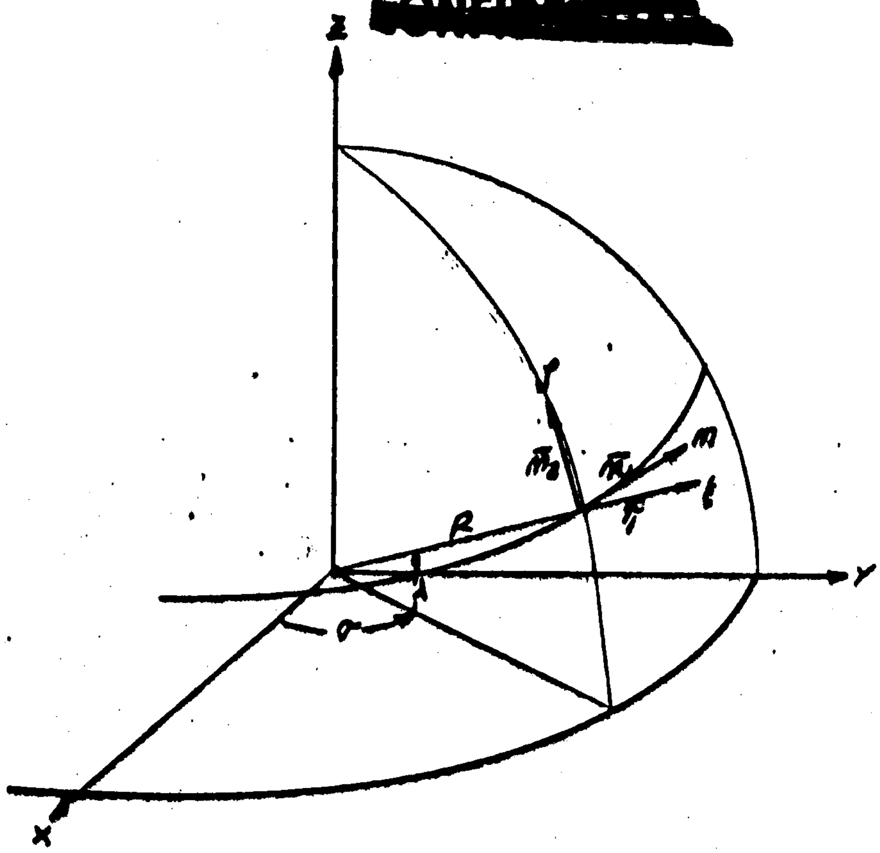


FIGURE 7 DEFINITION OF INERTIAL (X Y Z) AND LOCAL VERTICAL (ξ η ρ) COORDINATE SYSTEMS

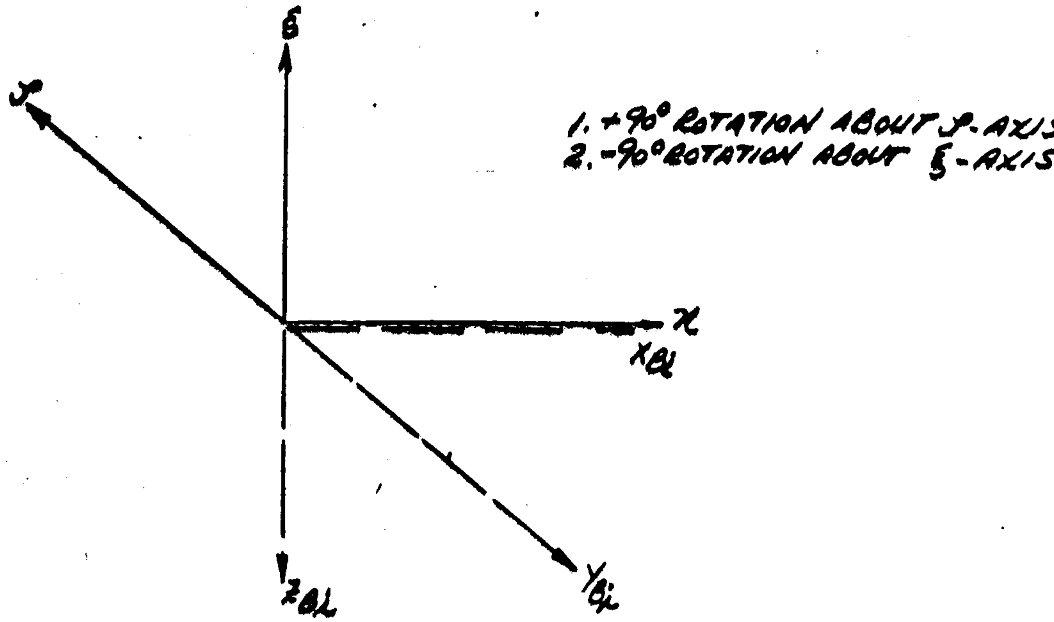


FIGURE 8 ORIENTATION OF INITIAL BODY (X_{BL} Y_{BL} Z_{BL}) AND LOCAL VERTICAL AXIS SYSTEM

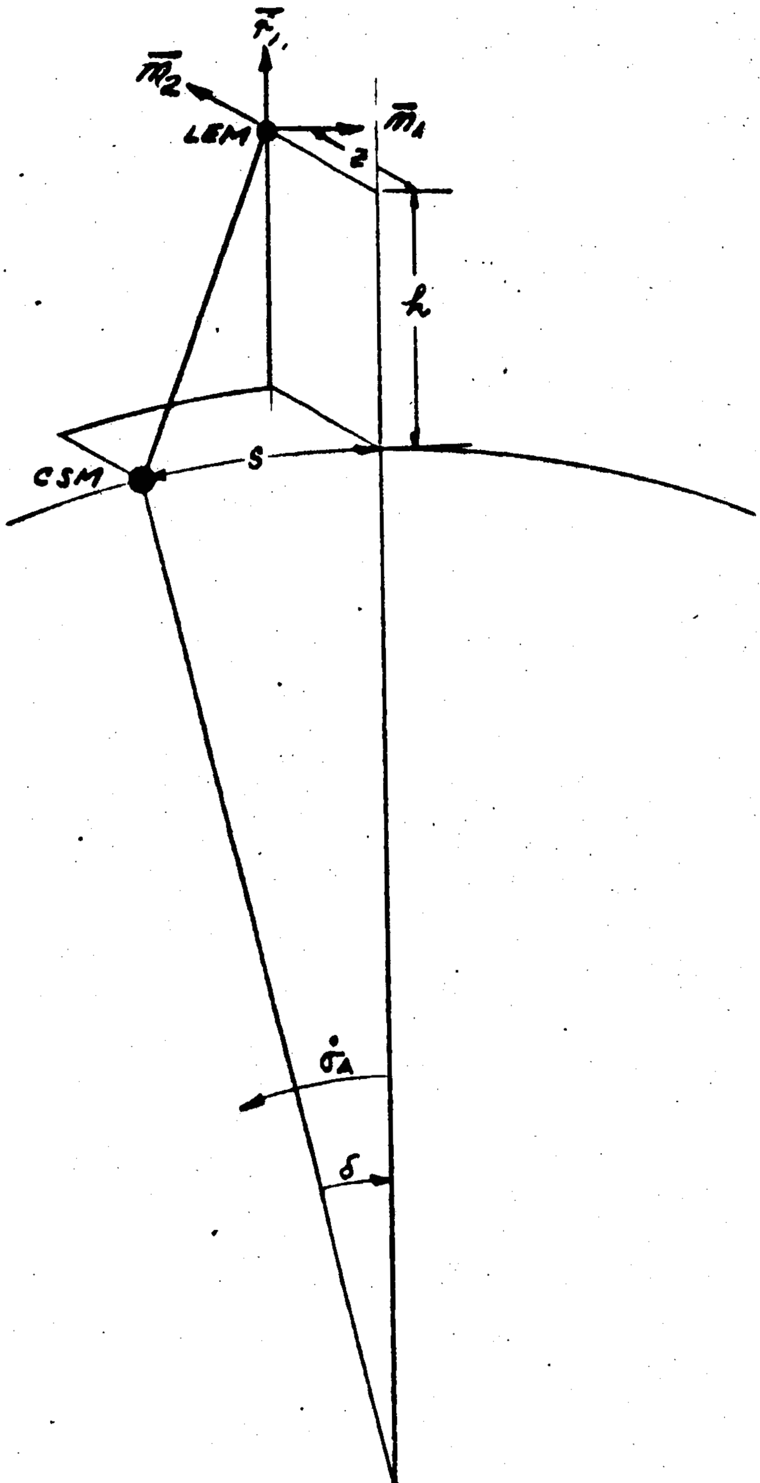


FIGURE 9 GEOMETRY OF TRANSLATIONAL EQUATIONS OF MOTION

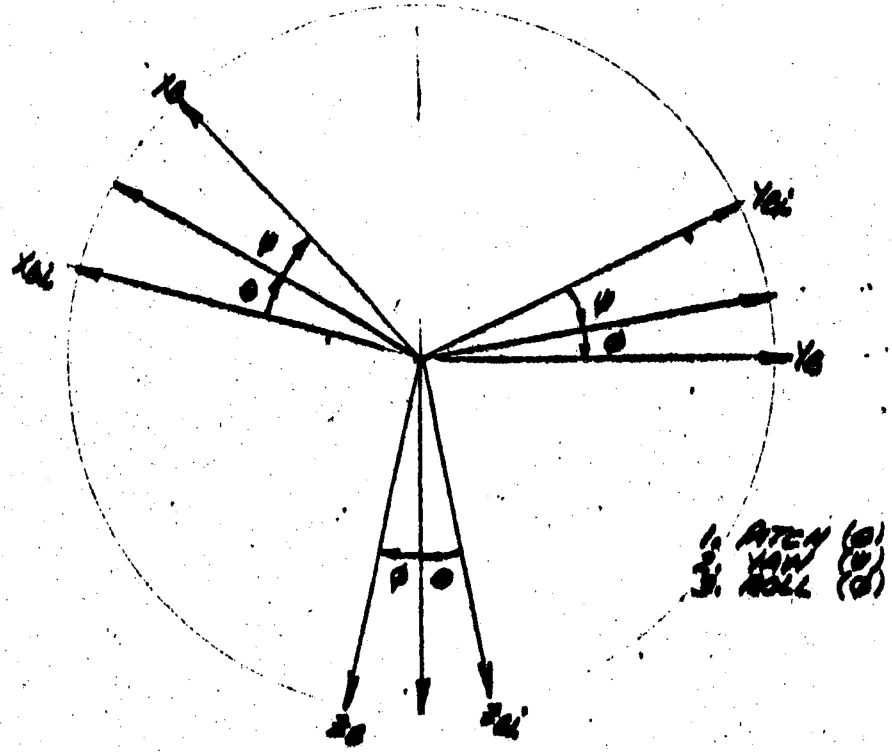


FIGURE 10 ORDER OF EULER ANGLE ROTATION

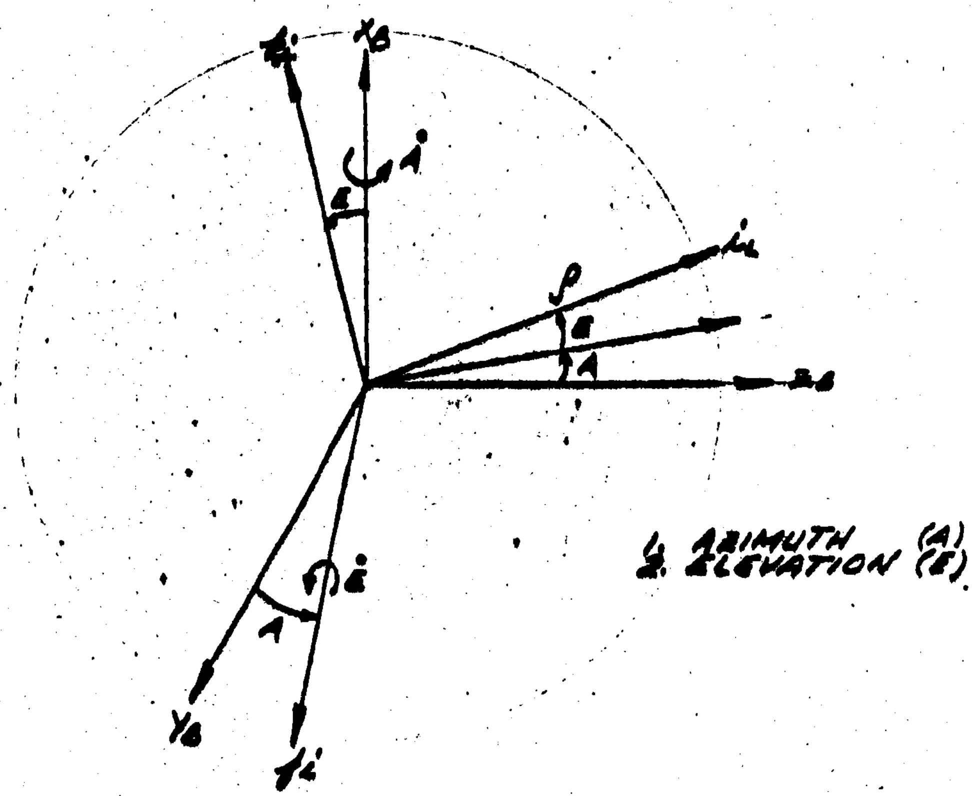
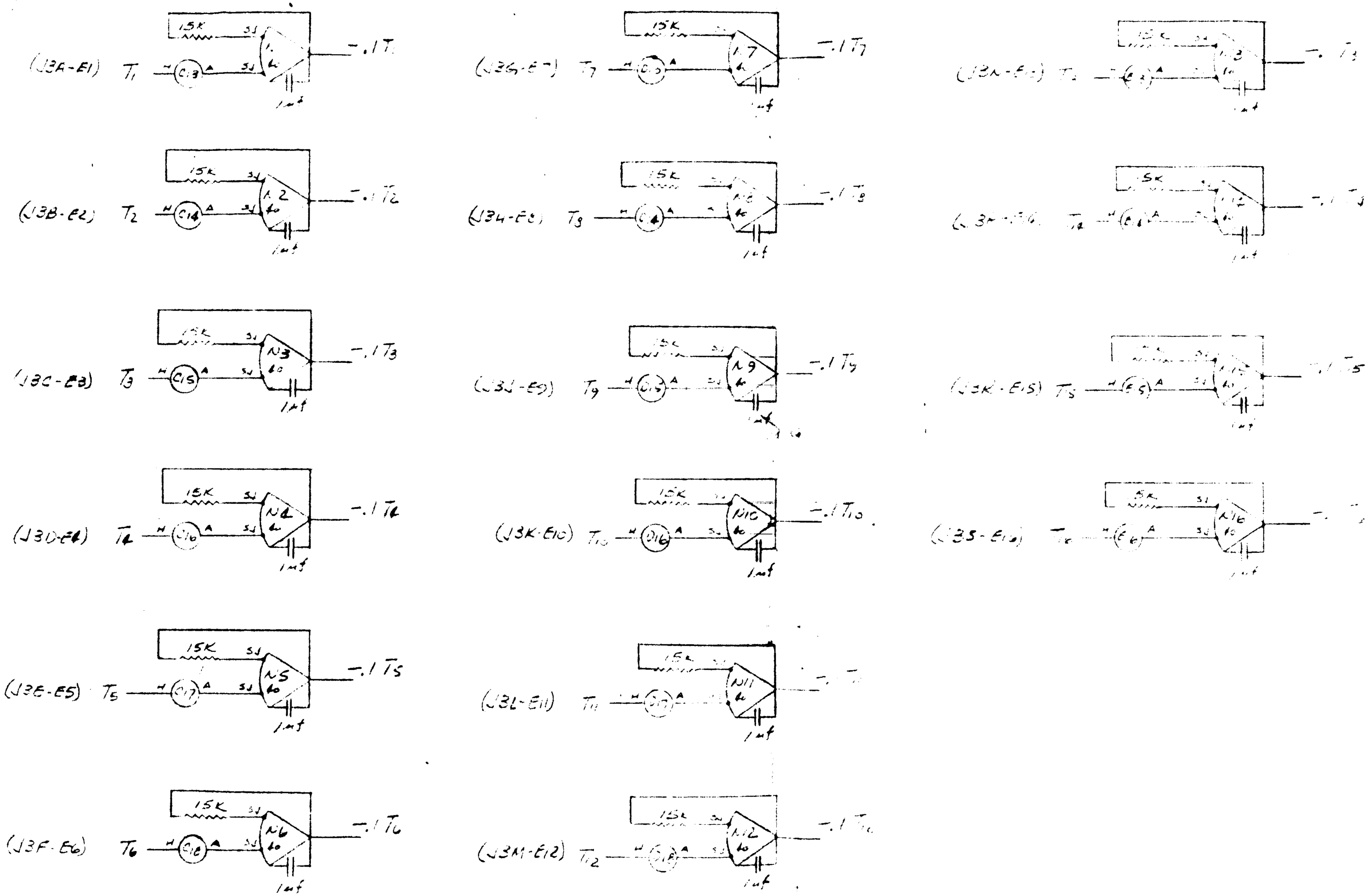


FIGURE 11 GEOMETRY OF LINE OF SIGHT



NOTE: ALL SCALE FACTOR POT LEVIS ARE OPEN.

FIGURE 12a

~~CONFIDENTIAL~~

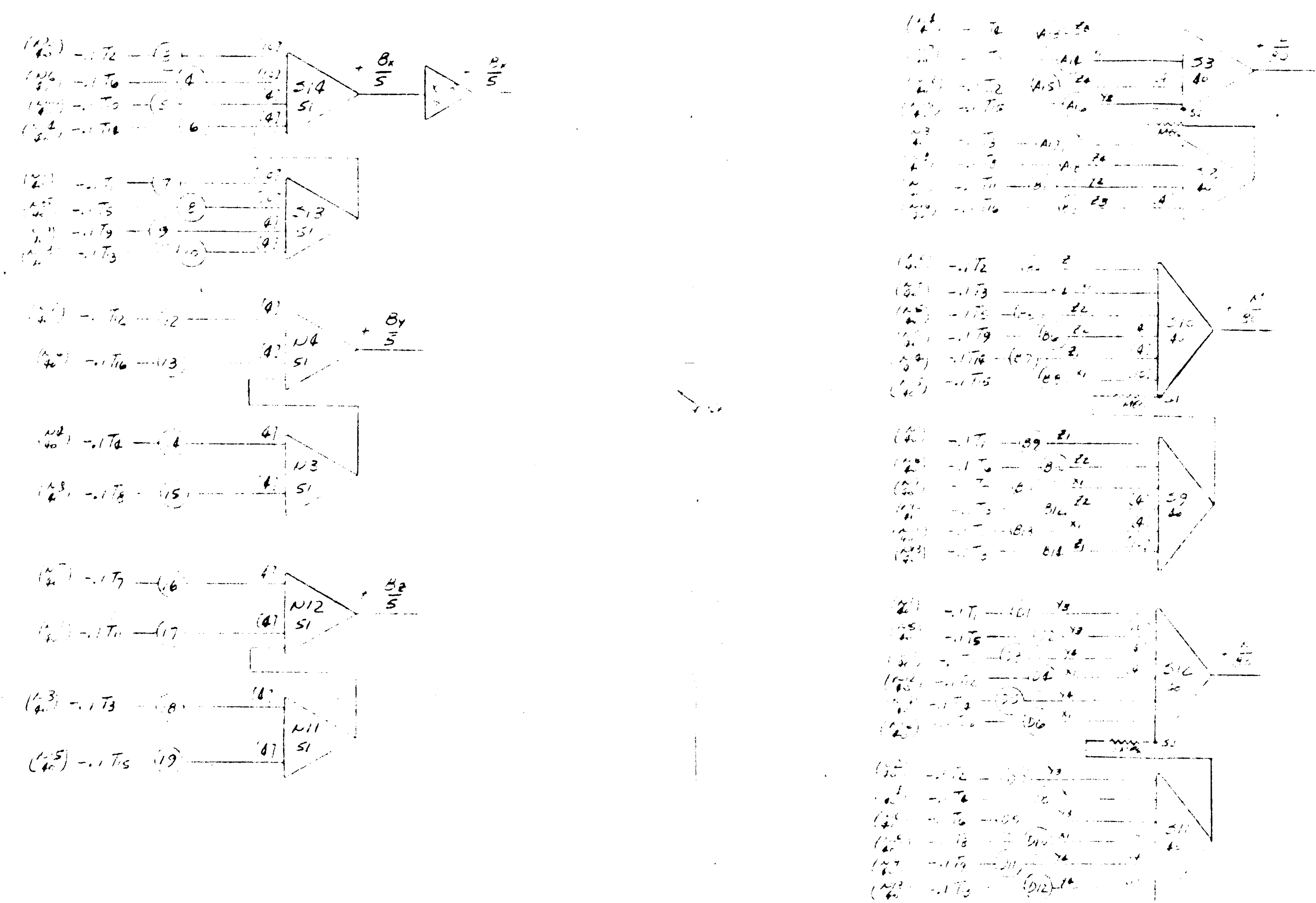


FIGURE 12b

~~CONFIDENTIAL~~

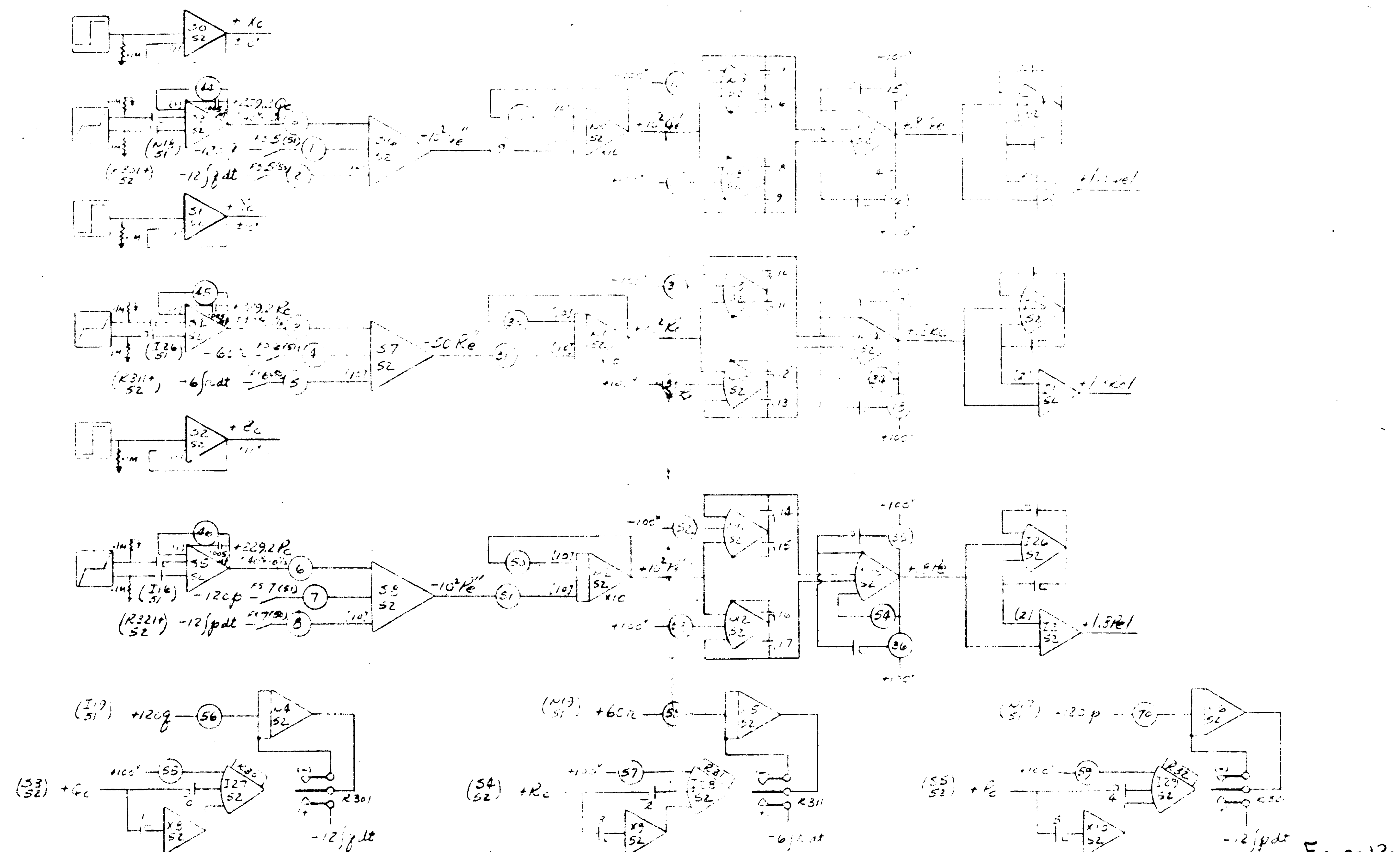


FIGURE 12c

~~CONFIDENTIAL~~

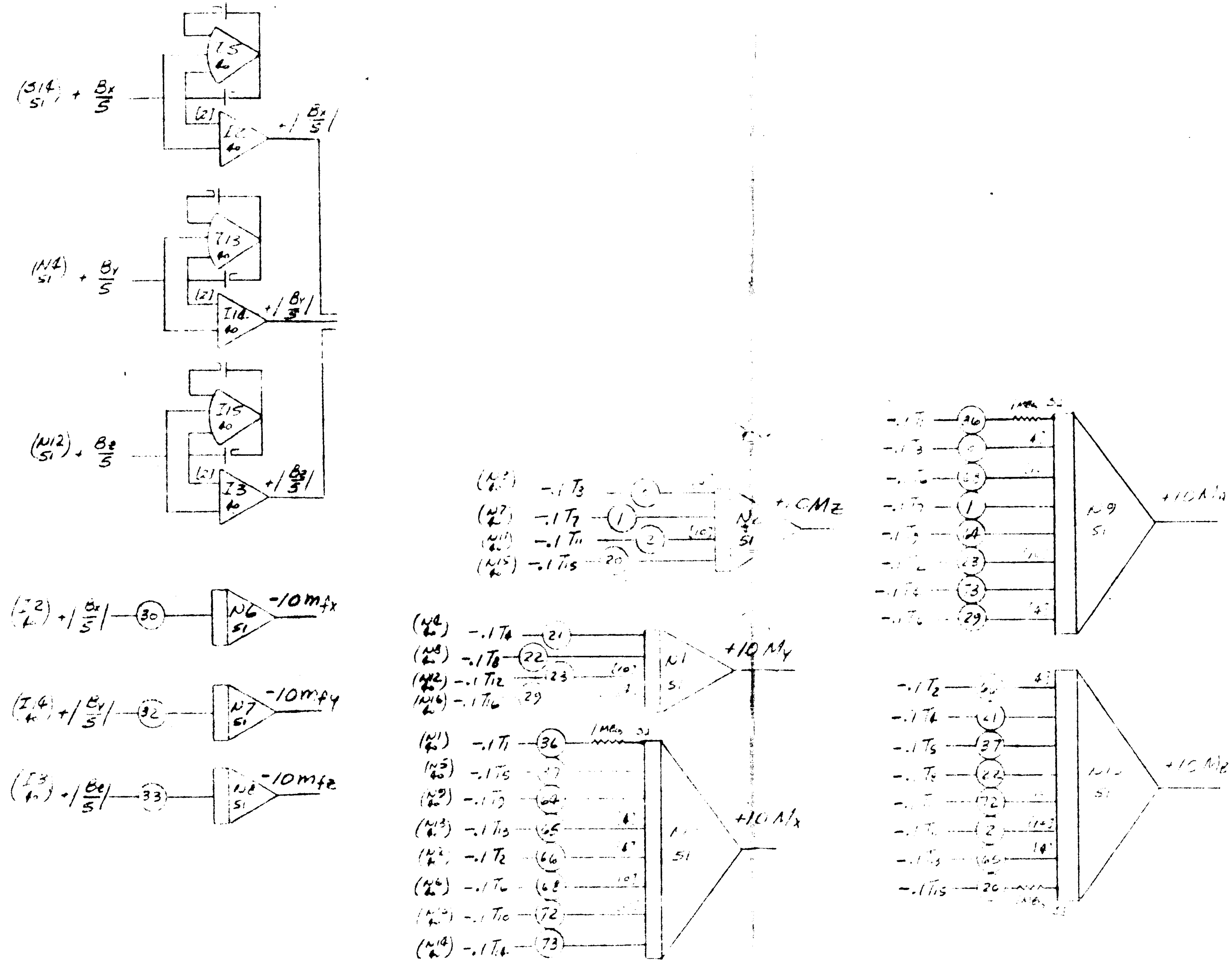


FIGURE 12d

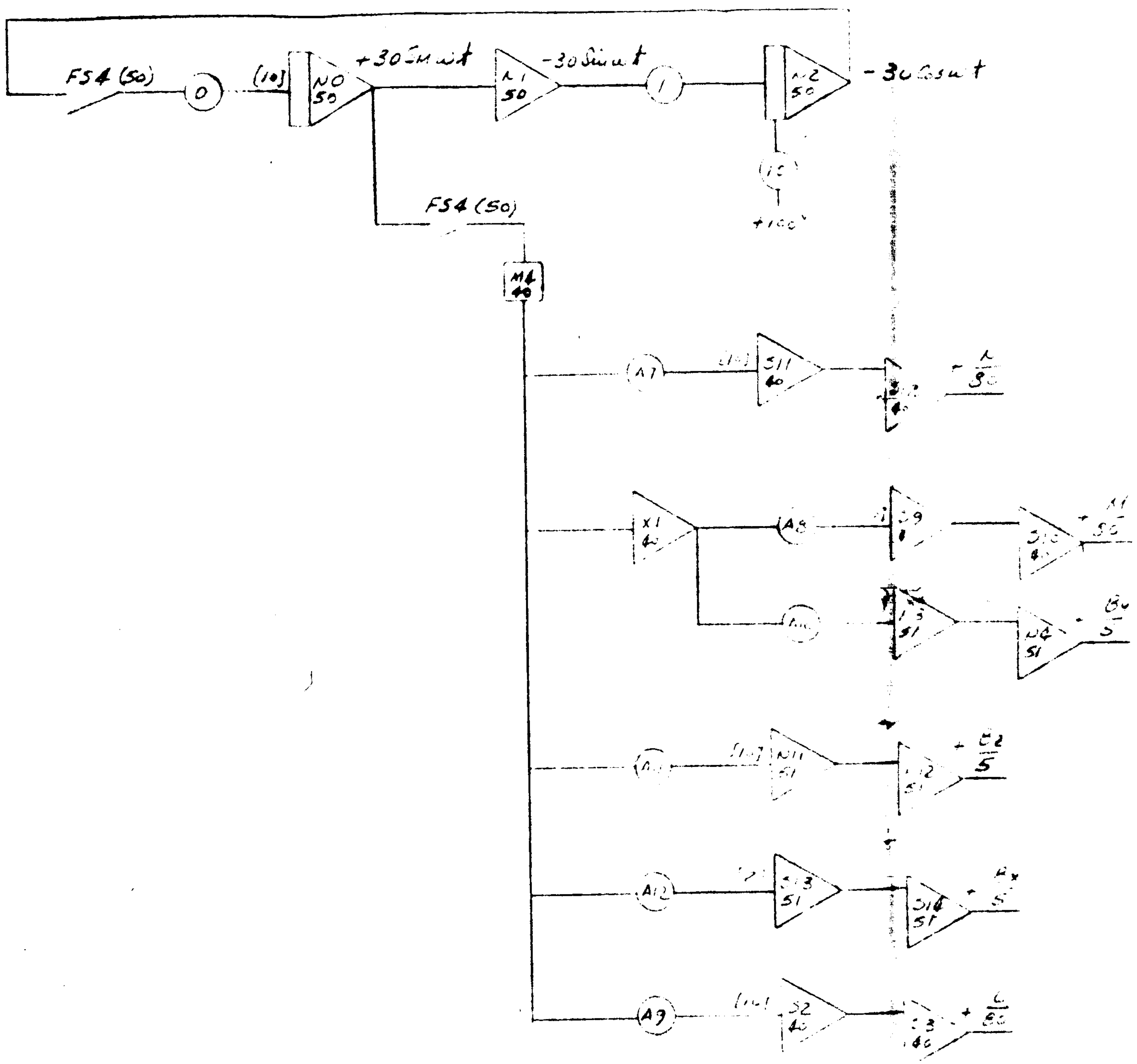

FS4 (50)
(10)
NO 50
+30 Cos ωt
N1 50
-30 Sin ωt
N2 50
-30 Cos ωt
+100
FS4 (50)
M4 40
A7
S11 40
A8
X1 40
A9
N11 51
A12
N4 51
S14 51
S2 40

FIGURE 12e

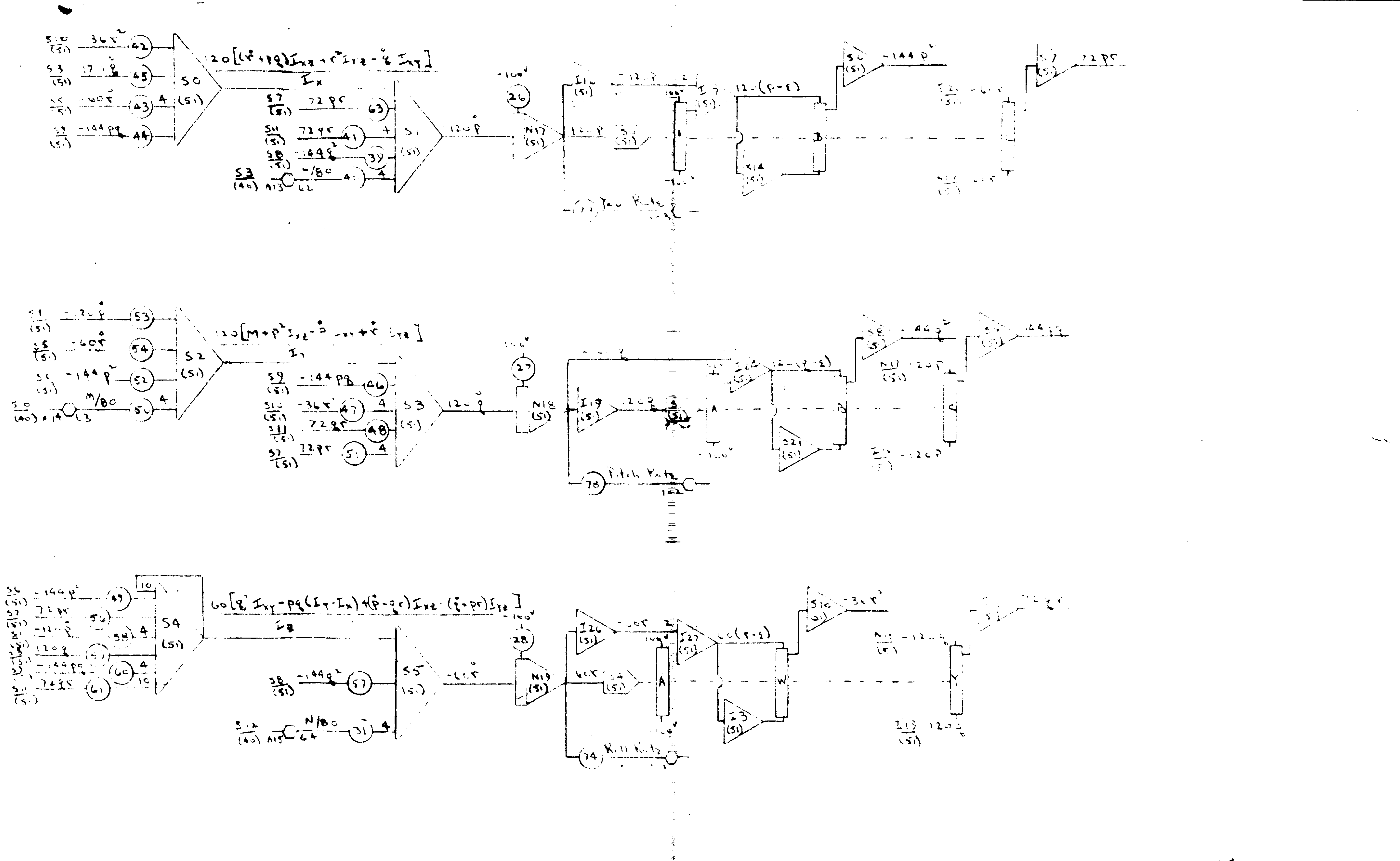


FIGURE 12f

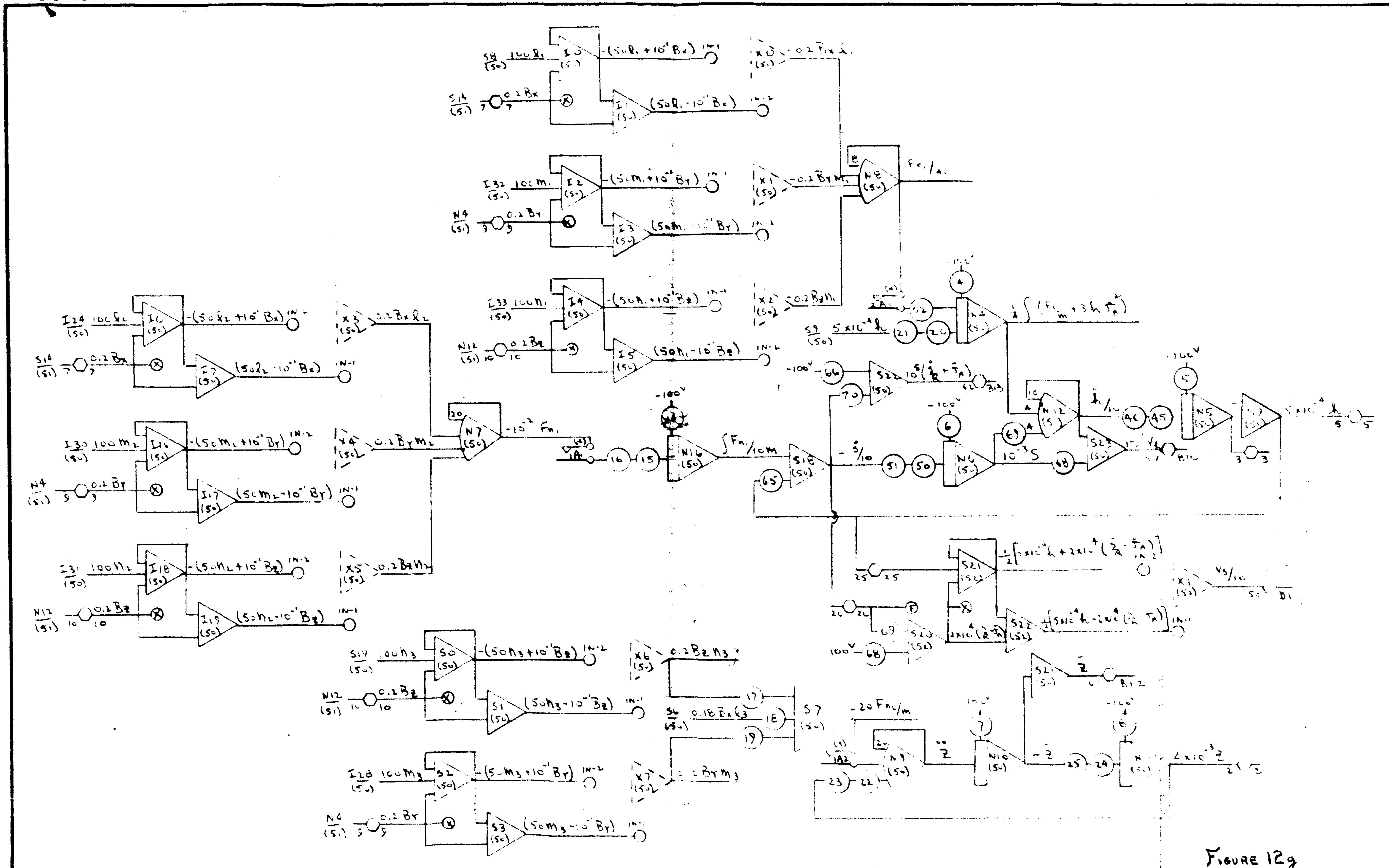


Figure 12g

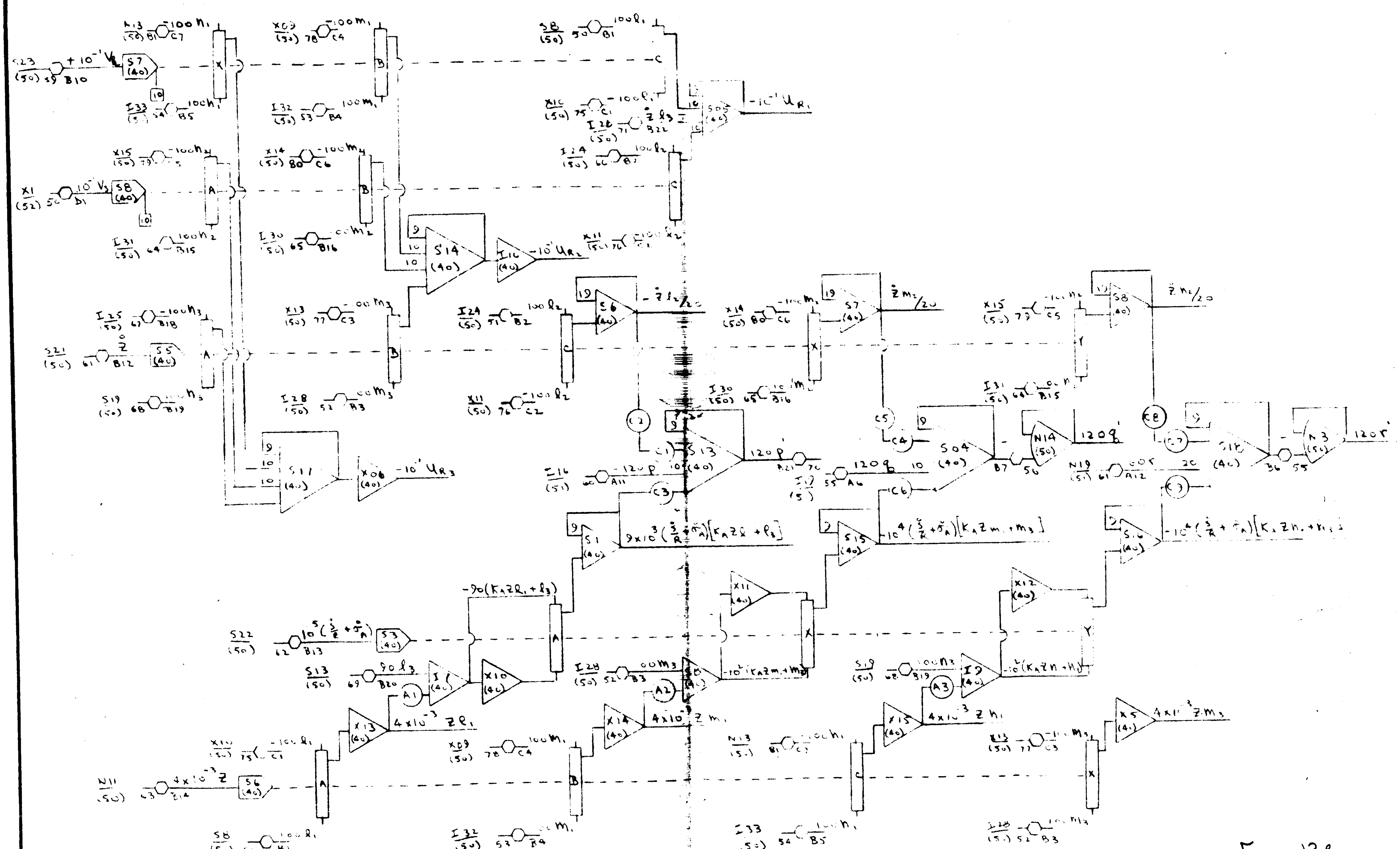

S7 (40)
S8 (40)
S5 (40)
S14 (40)
I10 (40)
$-10^{-1} U_{R_1}$
$-10^{-1} U_{R_2}$
$-10^{-1} U_{R_3}$
S11 (40)
X06 (40)
S6 (40)
S13 (40)
S7 (40)
S8 (40)
S04 (40)
N14 (50)
N3 (50)
S1 (40)
S15 (40)
X11 (40)
X12 (40)
X10 (40)
I9 (40)
X13 (40)
X14 (40)
X15 (40)
X5 (40)
S3 (40)
S6 (40)
$9 \times 10^{3}\left(\frac{\dot{s}}{R}+\dot{\sigma}_{A}\right)\left[K_A Z \ell_2 + \ell_3\right]$
$-10^{4}\left(\frac{\dot{s}}{R}+\dot{\sigma}_{A}\right)\left[K_A Z m_2 + m_3\right]$
$-90(K_A Z \ell_2 + \ell_3)$
$4 \times 10^{-3} Z \ell_1$
$4 \times 10^{-3} Z m_1$
$4 \times 10^{-3} Z h_1$
$4 \times 10^{-3} Z m_1$
$4 \times 10^{-3} Z$
$120\,p'$
$120\,q'$
$120\,r'$

Figure 12R

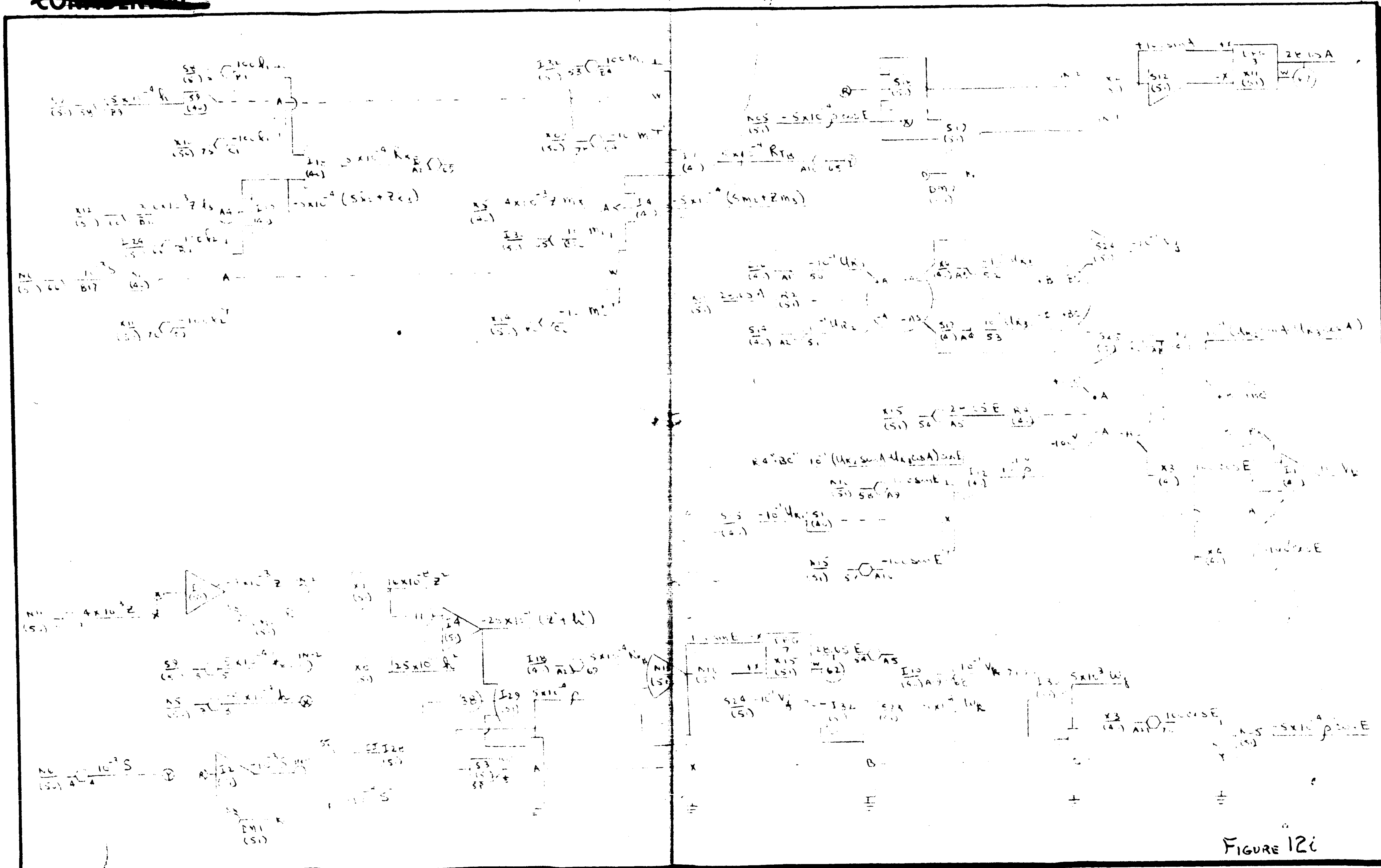


Figure 12i

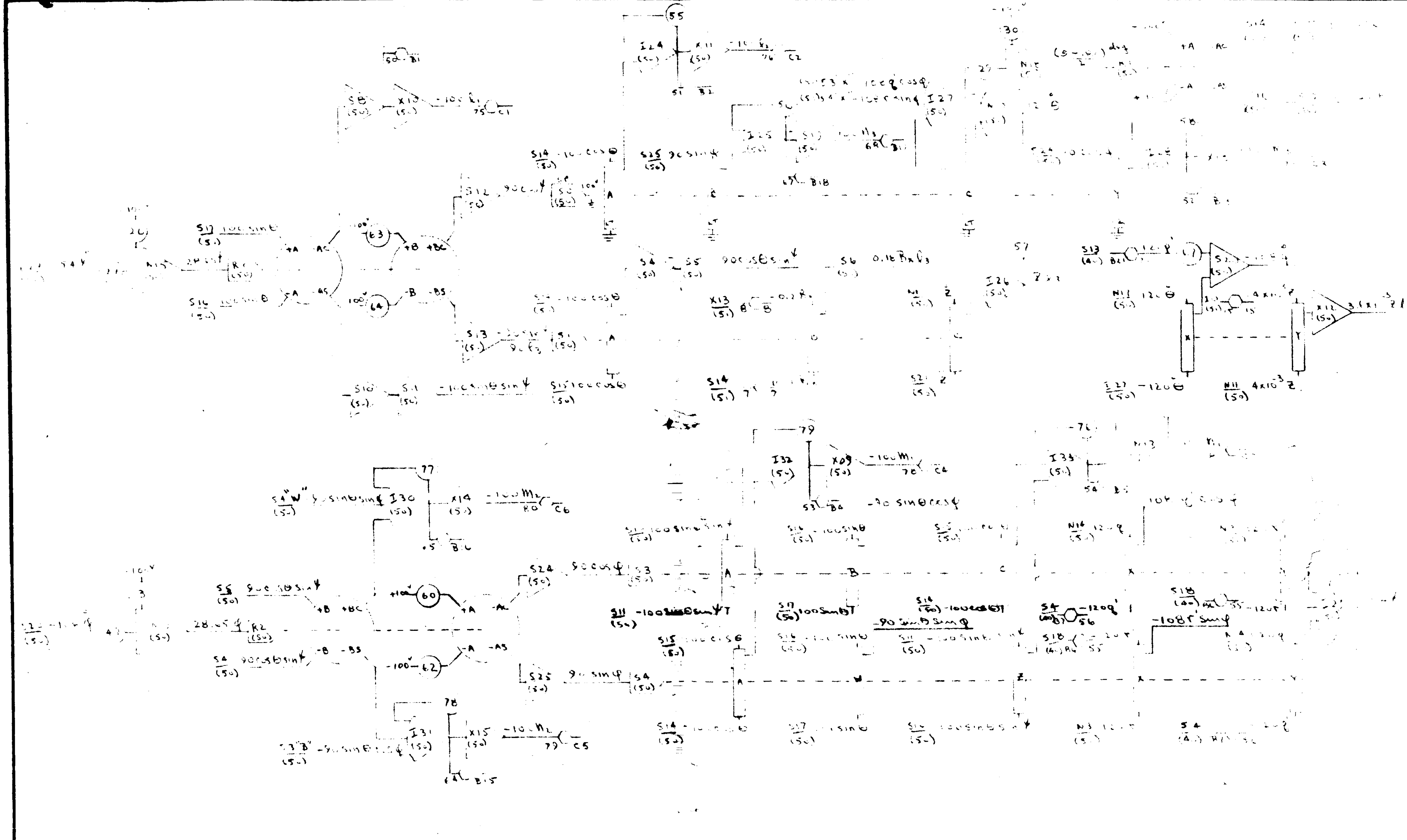


FIGURE 12j

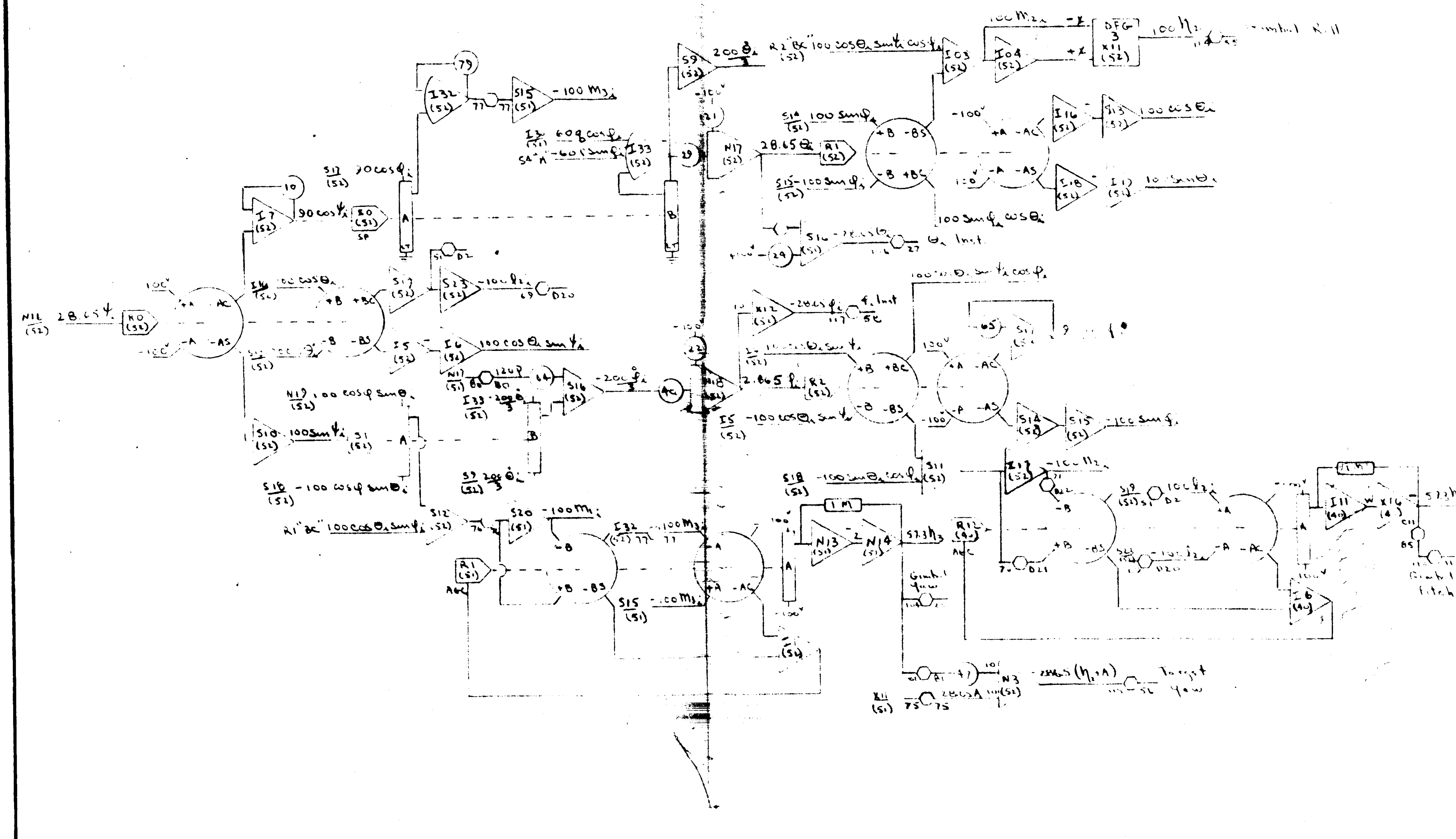

Gimbal Roll
Gimbal Yaw
Gimbal Pitch
Target Yaw
-100 M_{3i}
θ_i Init
ϕ_i Init

FIGURE 12k

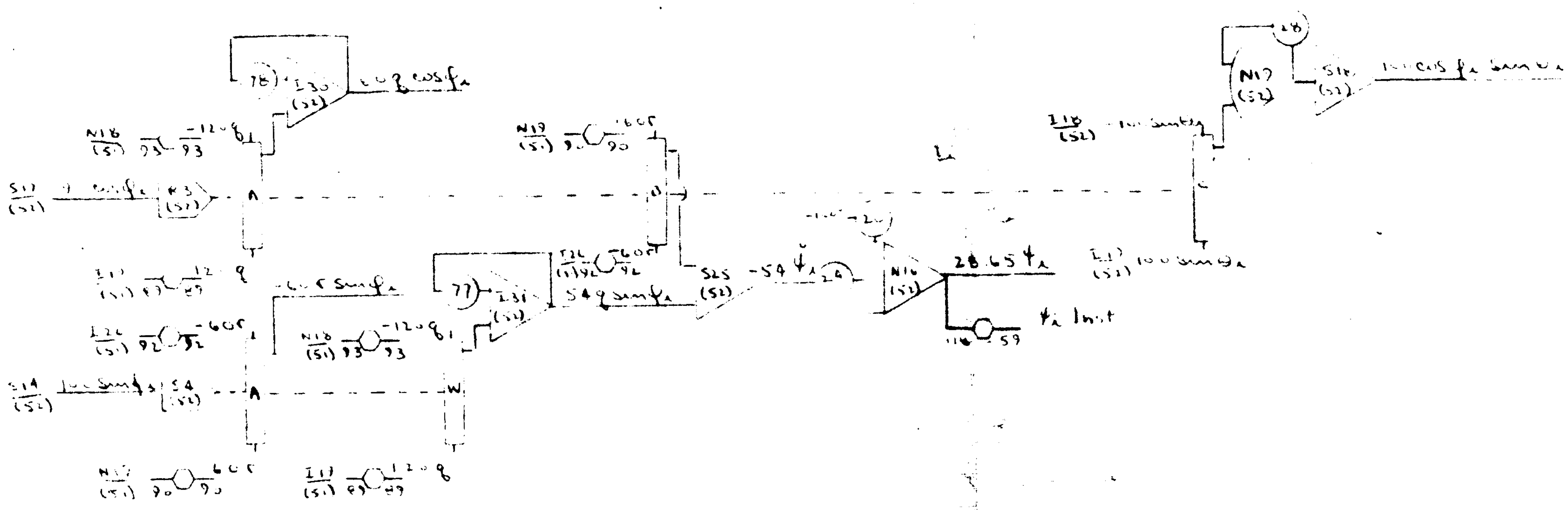


Figure 12l

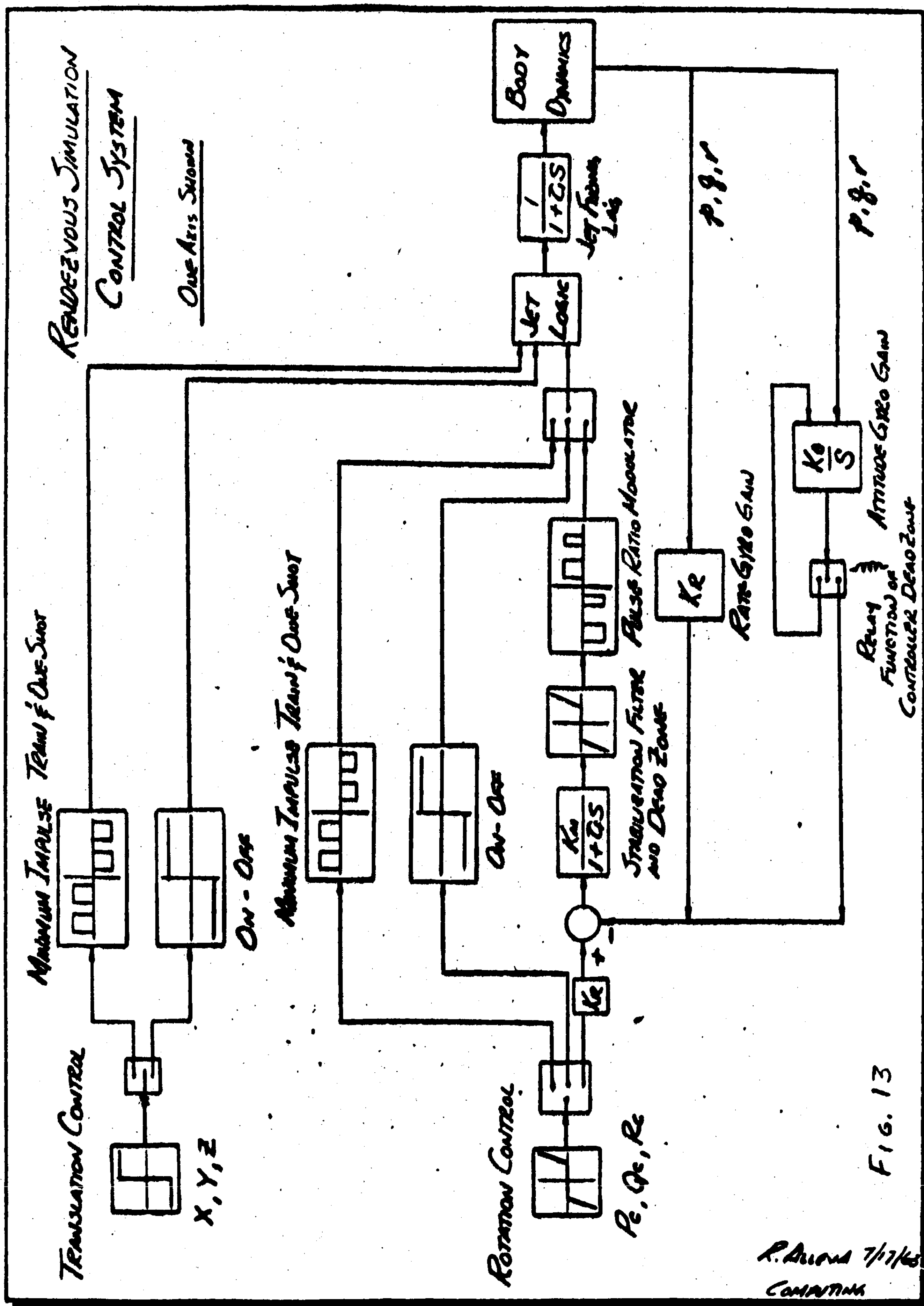


Fig. 13

R. Aliona 7/17/63
Computing

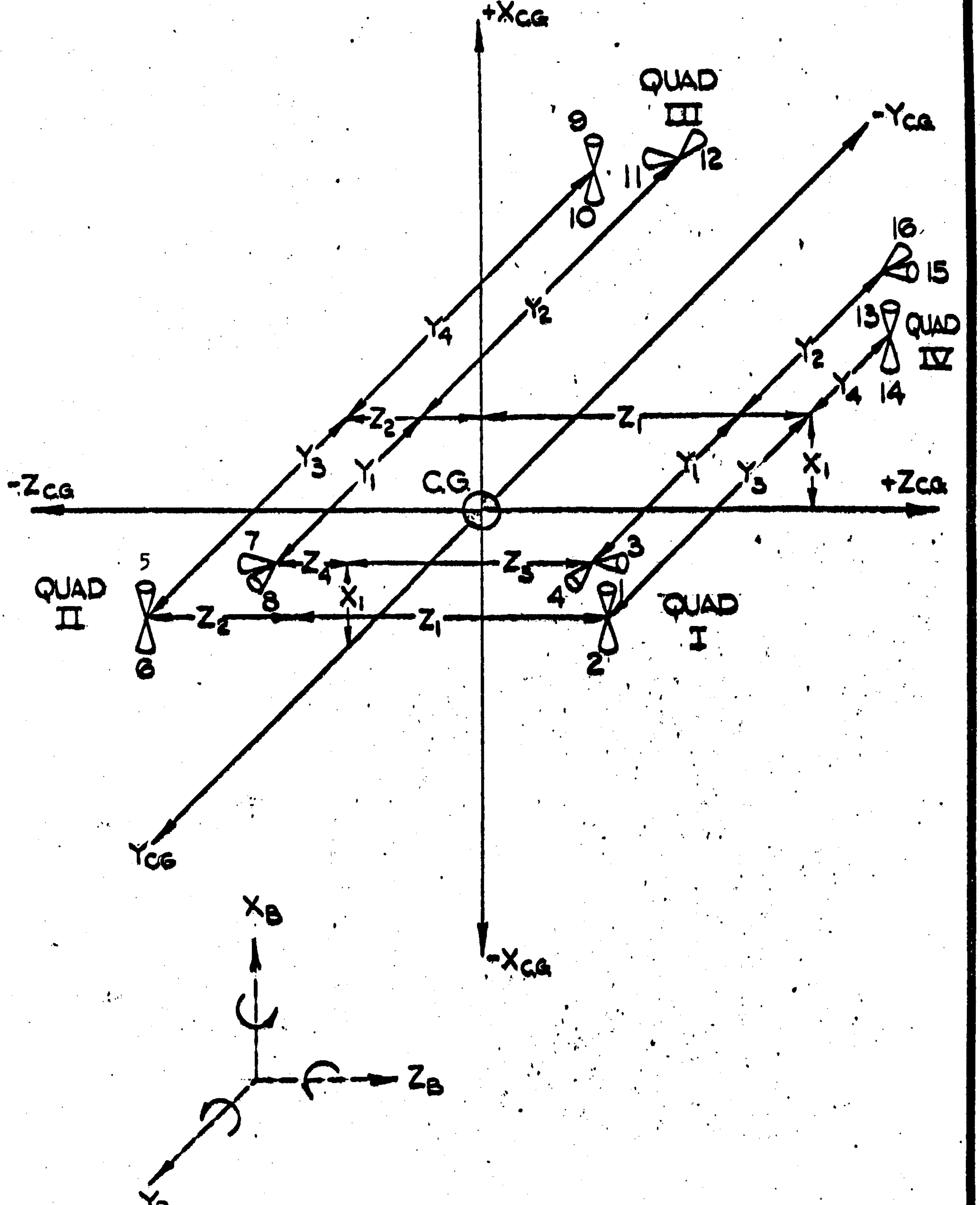


FIGURE 14 - RCS Moment Arms Definition

GLOSSARY

Term	Definition
Attitude Control	That portion of the flight control system which provides the dynamic forces upon the vehicle to cause attitude corrections, either manually or automatically
Bugs	Backup guidance system
Central Angle	The angular rotation (in degrees) of a body about the Lunar Center of Gravity as measured from some reference in this case the Landing Site - Lunar C. G. line
C. G.	Center of Gravity
Coplanar	Lying in the same plane
Correction Step	A nulling of the inertial LEM-CSM Line of sight rates and a bringing of the LEM-CSM Relative Range and Range Rate to specific values
CSM	Command Service Module
Direct	An open Loop, acceleration command attitude control mode
$d_{x, y, z}$	Modulator Deadzone (degrees)
e	Normalized Error
e_{sat}	Normalized Saturation Error
FCS	Flight Control System
FMES	Full Mission Engineering Simulator
FPS	Feet per second
fp	Pulse Frequency (pulses per second)
IC	Initial Condition
ILS	Indicated Line of Sight
IMU	Inertial Measuring Unit
K_{RS}	Attitude Controller Sensitivity (Gain) - $\left(\frac{\text{Degrees per Second}}{\text{Full Stick Throw}}\right)$
$K_{M_{x,y,z}}$	Modulator Gain

GLOSSARY (Continued)

Term	Definition
$K_{R_{x,y,z}}$	Rate Feedback Gain
$K_{x,y,z}$	Rate Integrator Feedback Gain
LEM	Lunar Excursion Module
LOS Rate Control	Reducing the rotational line of sight (LOS) Vector to Zero
Minimum Impulse	An open Loop, acceleration command attitude and translation control mode in which a train of minimum impulse bits are generated to provide dynamic vehicle forces
NOM	Nominal
nm	Nautical Miles
PNGS	Primary Navigation and Guidance System
QUAD	Set of Four RCS Jets
Range and Range Rate Control	Providing Dynamic forces to the vehicle in such a manner as to bring the relative range and range rate between the LEM-CSM to specific values
RCS	Reaction Control System (Reaction Jets)
SYNCH	Synchronous
Translation Control	That portion of the FCS which provides the dynamic forces upon the vehicle to cause it to move linearly along any of its several axes, either manually or automatically
White Noise	Gaussian noise of equal power density over entire frequency range with which we are herein concerned
WRT	With respect to
ξ_{FCS}	Flight Control System Damping Ratio
τ_{FCS}	Flight Control System Time Constant (seconds)
τ_{ω}	Pulse Width (milliseconds)
τ_{J}	Reaction Jet Time Constant (seconds)
ω_{N}	Flight Control System Natural Frequency (radians per second)

DEFINITION OF SYMBOLS - LEM RENDEZVOUS EQUATIONS

SYMBOL	DEFINITION	UNITS	SYMBOL	DEFINITION	UNITS
B_x	LEM Body Axis Force X_B Direction	Lbs.	m	LEM Mass	Slugs
B_y	LEM Body Axis Force Y_B Direction	Lbs.	$\dot{\sigma}_A$	Apollo Orbital Angular Velocity	Rad/Sec
B_z	LEM Body Axis Force Z_B Direction	Lbs.	ρ	Range	Ft
F_{r_1}	Local Vertical Force r_1 Direction	Lbs.	U_{R_1}	Relative Velocity in X_B Direction	Ft/Sec
F_{n_1}	Local Vertical Force n_1 Direction	Lbs.	U_{R_2}	Relative Velocity in Y_B Direction	Ft/Sec
F_{n_2}	Local Vertical Force n_2 Direction	Lbs.	U_{R_3}	Relative Velocity in Z_B Direction	Ft/Sec
$l_{1,2,3}$	Direction Cosines, Body to Local Vertical	-	$\dot{\rho}$	Range Rate	Ft/Sec
$m_{1,2,3}$	Direction Cosines, Body to Local Vertical	-	V_j	Line of Sight Velocity Along j_L Axis	Ft/Sec
$n_{1,2,3}$	Direction Cosines, Body to Local Vertical	-	V_k	Line of Sight Velocity Along k_L Axis	Ft/Sec
$\dot{S}$	Relative Velocity Between LEM and CSM Orbit Circle	Ft/Sec	$t_{1,2,3}$	Direction Cosines - Body to Line of Sight	-
S	Relative Displacement Along Arc of CSM Orbit Circle	Ft	$u_{2,3}$	Direction Cosines - Body to Line of Sight	-
$\dot{h}$	Radial Velocity Between LEM and CSM Orbit Circle	Ft/Sec	$V_{1,2,3}$	Direction Cosines - Body to Line of Sight	-
h	Radial Displacement From CSM Orbit Circle	Ft	ω_j	Line of Sight Inertial Angular Velocity	Rad/Sec
$\ddot{z}$	Relative Acceleration Normal to CSM Orbit	Ft/Sec^2	ω_k	Line of Sight Inertial Angular Velocity	Rad/Sec
$\dot{z}$	Relative Velocity Normal to CSM Orbit	Ft/Sec	A	Azimuth Angle	Rad
z	Relative Normal Displacement	Ft	E	Elevation Angle	Rad
δ	Relative Angular Displacement	Radians	L	Moment About X_B - Axis	Ft-Lbs

APPENDIX A (Cont.)

DEFINITION OF SYMBOLS - LEM RENDEZVOUS EQUATIONS

SYMBOL	DEFINITION	UNITS	SYMBOL	DEFINITION	UNITS
M	Moment About Y_B - Axis	Ft-Lbs	$\dot{\phi}_i$	Inertial Euler Angle Roll Rate	Rad/Sec
N	Moment About Z_B - Axis	Ft-Lbs	θ_i	Inertial Pitch Angle	Rad
$\dot{p}$	Angular Acceleration About X_B - Axis	Rad/Sec^2	ψ_i	Inertial Yaw Angle	Rad
$\dot{q}$	Angular Acceleration About Y_B - Axis	Rad/Sec^2	ϕ_i	Inertial Roll Angle	Rad
$\dot{r}$	Angular Acceleration About Z_B - Axis	Rad/Sec^2	p'	Angular Rate About X_B - Axis W.R.T. Local Vertical	Rad/Sec
p	Angular Rate About X_B - Axis	Rad/Sec	q'	Angular Rate About Y_B - Axis W.R.T. Local Vertical	Rad/Sec
q	Angular Rate About Y_B - Axis	Rad/Sec	r'	Angular Rate About Z_B - Axis W.R.T. Local Vertical	Rad/Sec
r	Angular Rate About Z_B - Axis	Rad/Sec	K_A	Constant	1/Ft
I_x	Inertia - X_B - Axis	Slug-Ft^2	$\dot{\theta}$	Euler Angle Pitch Rate W.R.T. Local Vertical	Rad/Sec
I_y	Inertia - Y_B - Axis	Slug-Ft^2	$\dot{\psi}$	Euler Angle Yaw Rate W.R.T. Local Vertical	Rad/Sec
I_z	Inertia - Z_B Axis	Slug-Ft^2	$\dot{\phi}$	Euler Angle Roll Rate W.R.T. Local Vertical	Rad/Sec
I_{xy}	Inertia Cross - Product	Slug-Ft^2	θ	Pitch Angle W.R.T. Local Vertical	Rad
I_{yz}	Inertia Cross - Product	Slug-Ft^2	ψ	Yaw Angle W.R.T. Local Vertical	Rad
I_{xz}	Inertia Cross - Product	Slug-Ft^2	ϕ	Roll Angle W.R.T. Local Vertical	Rad
$\dot{\theta}_i$	Inertial Euler Angle Pitch Rate	Rad/Sec	T_J J=1...12	Reaction Jet Thrusts	Lbs.
$\dot{\psi}_i$	Inertial Euler Angle Yaw Rate	Rad/Sec	$X_{J,B}$	Reaction Jet Moment Arms in X_B Direction	Ft

APPENDIX A (Cont.)

DEFINITION OF SYMBOLS - LEM RENDEZVOUS EQUATIONS

SYMBOL	DEFINITION	UNITS
$Y_{1,2,3,4}$	Reaction Jet Moment Arms in Y_B Direction	Ft
$Z_{1,2,3,4}$	Reaction Jet Moment Arms in Z_B Direction	Ft
m_x	Reaction Jet Fuel Consumed in X_B Direction	Slugs
m_y	Reaction Jet Fuel Consumed in Y_B Direction	Slugs
m_z	Reaction Jet Fuel Consumed in Z_B Direction	Slugs
m_{I}	Reaction Jet Fuel Consumed in Quad I (Fig. 4)	Slugs
m_{II}	Reaction Jet Fuel Consumed in Quad II	Slugs
m_{III}	Reaction Jet Fuel Consumed in Quad III	Slugs
m_{IV}	Reaction Jet Fuel in Quad IV	Slugs
V_s	Relative Velocity in LEM Local Horizontal Direction	Ft/Sec
V_h	Relative Velocity in LEM Local Vertical Direction	Ft/Sec
R_{xB}	Relative Position In LEM X_B - Direction	Ft
R_{yB}	Relative Position In LEM Y_B - Direction	Ft

SYMBOL	DEFINITION	UNITS
M_x	Translational RCS Fuel Consumed in X Direction	Slugs
M_y	Translational RCS Fuel Consumed in X Direction	Slugs
M_z	Translational RCS Fuel Consumed in X Direction	Slugs
M_A	Reaction Jet Fuel Consumed in RCS System A	Slugs
M_B	Reaction Jet Fuel Consumed in RCS System B	Slugs